

Implications of Automotive and Trucking On-Board Information Systems for General Aviation Cockpit Weather Systems

*Yesim Sireli and Paul Kauffmann
Old Dominion University, Norfolk, Virginia
Surabhi Gupta and Pushkin Kachroo
Virginia Tech, Blacksburg, Virginia*

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NAG-1-2278

January 2002

Acknowledgements

We would like to thank NASA Aviation Safety Program for sponsoring this research (grant number: NAG-1-2278), and Langley Technical Officer Edward Johnson for his support and guidance during this project.

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Contents

Contents.....	2
Abstract.....	4
1 Introduction	4
2 Intelligent Transportation Systems (ITS) and Their Development	5
2.1 Definitions of ITS	5
2.2 Historical Development of ITS Programs in Europe, Japan, and the U.S.A.....	6
2.2.1 European Union Initiatives	6
2.2.2 Japanese Initiatives.....	7
2.2.3 The U.S. Initiatives.....	8
2.3 Summary of ITS Historical Development	9
2.4 Technical Issues in Intelligent Transportation Systems Deployment.....	12
3 Automobile and Trucking Industry Products	14
3.1 Interface Technologies	14
3.1.1 In-Vehicle Information Systems (IVIS)	14
3.1.2 Display Technology.....	15
3.1.2.1 Liquid Crystal Display (LCD).....	15
3.1.2.2 Organic LED Display.....	15
3.1.2.3 Night-Vision and Head-Up Display Technology	16
3.1.3 Speech Recognition Technology.....	16
3.1.4 User Interfaces.....	17
3.2 Services.....	18
3.3 Product and Service Costs	18
3.4 Summary of Products Used in Automotive and Trucking Industry and Their Features.....	19
3.5 Future Developments on Existing Products	22
4 Enabling Communications Technologies.....	24
4.1 Wireless Data Networks	24
4.1.1 Private Mobile Radio Networks	25
4.1.1.1 Motient	25
4.1.1.2 BellSouth Mobitex Network	26
4.1.2 Multichannel Multipoint Distribution Service (MMDS).....	27
4.1.3 Satellite Data Networks	27
4.1.3.1 Teledesic.....	28
4.1.3.2 Globalstar	29
4.1.3.3 Inmarsat.....	30
4.1.3.4 Connexion by Boeing SM	30
4.1.3.5 Propagation Effects in Mobile Satellite Systems	31
4.1.4 Satellite Digital Audio Radio Services (S-DARS).....	31
4.1.4.1 Companies offering S-DARS	32
4.1.4.2 Future Planned Capabilities of S-DARS.....	32
4.1.5 Third Generation Cellular Networks (3G).....	33
4.1.5.1 S-UMTS	35
4.2 Device Technologies for Wireless Connectivity.....	36
4.2.1 Operating Systems.....	36
4.2.2 Air Interface / Wireless Modem.....	37

4.2.3 Bluetooth.....	37
4.3 Challenges to Deployment of Wireless Technologies and Some Solutions.....	38
Robust modulation that overcome degradation due to phase noise and coherent de-modulation.	39
5 Market Analysis and Technological Implications for General Aviation	40
5.1 Oshkosh Survey Analysis	40
5.1.1 Current Weather Related Equipment.....	41
5.1.2 Display Hardware.....	43
5.1.3 Preferred Features in the Future Equipment	44
5.1.4 Non-Recurring Costs	46
5.1.5 Recurring Costs	47
5.1.6 Survey Analysis.....	48
5.2 GPS Market Acceptance.....	49
5.2.1 Historical Development of GPS.....	50
5.2.2 Worldwide GPS Market Projections and Trends in Car Navigation and Aviation Markets	50
5.2.3 GPS Aviation Market	53
5.3 Current General Aviation Market Activities and Products	54
5.4 Technological Implications of Automobile and Trucking Information Systems for General Aviation.....	55
5.4.1 Software Radios	57
6 Conclusions and Recommendations	58
Abbreviations.....	62
References	65
Appendix A – Another Weather Information Product: TeleType GPS.....	67

Abstract

In this study, current characteristics and future developments of Intelligent Transportation Systems (ITS) in the automobile and trucking industry are investigated to identify the possible implications of such systems for General Aviation (GA) cockpit weather systems. First, ITS are explained based on tracing their historical development in various countries. Then, current systems, and the enabling communication technologies are discussed. Finally, a market analysis for GA is included.

1 Introduction

A broad range of the automobile and trucking industry currently employs on-board, computer-driven information systems. Key elements that supported penetration of this information system market, such as data link technologies, information system development, and costs, can have implications for cockpit weather system penetration in the General Aviation (GA) market.

In this report, current information systems used in the automobile and trucking industry, and the enabling communication technologies that supported those systems are discussed. The main objective is to identify the implications of automotive and trucking on-board information systems for general aviation cockpit weather systems, by investigating similar existing systems. The study was conducted jointly by the Department of Engineering Management at Old Dominion University and the Department of Electrical Engineering at Virginia Tech.

Two important focus areas of this study are advanced traveler information systems and commercial vehicle operations in the automobile and trucking (A/T) industry. The former better defines the systems in the automobile industry, and the latter in the trucking industry. These systems are referred as A/T in-vehicle or on-board information systems for the rest of this study. The study examines the current in-vehicle information systems market in the A/T industry in order to determine these systems' key characteristics, typical costs, and the future developments. Next, enabling communications technologies, which are selected based on this A/T industry market search and their possible availability for application in GA, will be discussed, including the challenges in deployment of wireless technologies and possible solutions. Finally, the results of these discussions are stated in conclusions at the end of this report. The next chapter examines Intelligent Transportation Systems.

2 Intelligent Transportation Systems (ITS) and Their Development

This section classifies the functional areas in ITS, compares historical development of ITS programs in Japan, Europe, and the U.S., and identifies technical issues in ITS deployment.

2.1 Definitions of ITS

To provide context, the study of ITS begins with examination of several definitions. Intelligent Transportation Systems (ITS) are in-vehicle information systems that combine information processing, communications, control, and electronics. The purpose of these systems is to improve safety, and decrease on-route time and money consumption (ref. 1). Telematics is another term that is used to describe this area and ITS America (ITSA) provides the following definition: Telematics refers to the consumer products, services and supporting systems that deliver information, communications and entertainment to in-vehicle and mobile devices (ref. 1). Based on these definitions, this report employs the following difference between ITS and telematics: ITS is the broad infrastructure, products and services, that can be in-vehicle as well as on the road and whose function is to aid transportation. Telematics is specifically the in-vehicle component of ITS and includes non-transportation functions as well (such as entertainment). ITS are discussed first in this chapter and several following chapters. Telematics is mentioned in a number of following sections, along with a similar term "In-Vehicle Information Systems" (IVIS), which are the specific on-board information systems that this study focuses on.

According to ITSA, there are five functional areas in ITS (refs. 2 and 3):

Advanced Traffic Management Systems (ATMS) involve the use of sophisticated technologies to manage the traffic on the transport network. These systems include traffic control systems, freeway ramp metering, and incident management systems.

Advanced Traveler Information Systems (ATIS) provide information directly to the traveler. Route guidance, navigation, personal messaging (such as emailing via Internet), location of nearby restaurants, or hotels, etc. are examples of ATIS.

Advanced Vehicle Control Systems involve computer control of the vehicle so that it can travel along the highway without human intervention. This area involves collision warning systems and intelligent cruise control.

Commercial Vehicle Operations involve the use of automatic vehicle location systems to permit intelligent management of commercial vehicle fleets. These systems provide more efficient dispatch and scheduling, as well as increased driver safety.

Advanced Public Transportation Systems involve the development of special – purpose public transport information and control systems. These systems provide passengers with information on the arrival times of buses or trains, allow smart card payment of fares, and improve operational efficiency.

The primary focus areas of this study are ATIS, and commercial vehicle operations in A/T industry. The former better defines the systems in the automobile industry, and the latter in the trucking industry. The next section introduces ITS programs in Europe, Japan, and the United States to provide information about similarities of these programs and their historical development.

2.2 Historical Development of ITS Programs in Europe, Japan, and the U.S.A.

There are major research and development programs on ITS in the United States, Europe, and Japan (refs. 3 and 4). This section introduces these programs, explains the similarities between them, and includes a comparative summary in a template format.

2.2.1 European Union Initiatives

The first concept of ITS developed in Europe was known as advanced transport telematics (ATT), and relied on a decentralized or autonomous transportation approach (ref. 4). In the 1980s, vehicle manufacturers began to realize the limitations imposed by the increasing volume of vehicles in the European transport network. The limitations were due to urban congestion, increased cost from time devoted to traveling, accidents, safety, security, environmental pollution and the need to use driving time more efficiently. Subsequently, manufacturers envisioned the possibility of a new transport system based on the application and integration of electronics, computers and telecommunications to reduce these limitations. This resulted in a research program entitled "PROgramMs for a European Traffic with a Highest Efficiency and Unprecedented Safety: PROMETHEUS."

PROMETHEUS began in 1986 with an 8 - year life span. The initial stage of the program (1986 - 1987) was a definition phase. There were initially 15 European vehicle manufacturers, but at the later stages, the program included other research projects sponsored by a number of research institutions. In 1988, the launch phase was implemented, with the first project demonstrations and in 1989 the research component was initiated. The annual funding was US\$113 million with two-thirds provided by industry and one-third by national ministries of technology, research and industry. PROMETHEUS led to the development of several demonstrator programs called Common European Demonstrators (CEDs). Each was formed to represent a near prototype stage of research in a particular area. Some of these were systems such as collision short-range communication, route guidance, fleet management, and traffic and travel information. The prototypes were usually served as technological demos, showing the practicability of taking systems originally developed in other domains such as military and aircraft / aerospace technology, and then integrate them into land transport. Members of CEDs programs were vehicle manufacturers such as Daimler-Benz, Ford, Volvo, BMW, Fiat, Renault, Opel, and industrial and research establishments such as GEC-Marconi, IBM, Nokia, Husat, Motorola, Philips, Bosch, and Lucas.

In 1988, a parallel program entitled DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) was adopted by the European Union as an R&D program in transport telematics and informatics. The objectives were the improvement of road safety, maximization of transport efficiency, and contribution to environmental quality.

The technologies to implement ITS in Europe were varied and developed by different organizations. The European Union Commission determined the major players in ITS to create a public - private organization in which participants could work together to make ITS a reality. Therefore, in 1991, the European Road Transport Telematic Implementation Coordination Organization (ERTICO) was formed. ERTICO conducts strategic planning for ITS implementation, analyzes needs and market of ITS, initiates and participates implementation projects.

PROMETHEUS, and DRIVE were concluded in 1994. However, other programs such as the 4th FRAMEWORK are presently in progress (based on 1997 data). There are also a number of national programs initiated by individual state governments. All of these programs execute systems integration,

2.2.2 Japanese Initiatives

In the 1970s, Japan identified that traffic problems such as congestion and increased road deaths were occurring due to the fast industrial growth and rapid development of cities (ref. 4). During the middle 1970s, Japan worked on improving highways and traffic control systems; and in the 1980s, the Japanese ITS initiative was officially started. National agencies, universities, research institutes, and private companies worked on projects such as:

- Advanced Mobile Traffic Information and Communication Systems (AMTICS),
- Road – Automobile Communication Systems (RACS),
- Vehicle Information and Communication System (VICS),
- Super Smart Vehicle System (SSVS).

The following paragraphs describe these programs:

AMTICS is sponsored by the National Police Agency and supported by the Ministry of Post and Telecommunications. There are approximately 60 private companies participating in the project through the Japan Traffic Management Technology Association. AMTICS is designed for route guidance and information in urban areas and employs an in-vehicle navigation system that uses teleterminals, which is similar in operation to cellular radios, for communication between the navigation system and traffic control center. The project was launched in 1987, and pilot tests were carried out in Tokyo in 1988 and later in 1990. The system is capable of displaying on screen all traffic information collected at traffic control and surveillance centers managed by the police in 74 cities. It displays the vehicle location, route guidance and information on traffic congestion, road works, and parking, location of major facilities, and emergency information of weather conditions.

RACS is a joint program involving the Public Works Research Institute of the Ministry of Construction and 25 private companies. It is coordinated by the National Police and the Ministry of Construction. The program was funded with 2 billion Yen and tests were started in 1987 and ended in 1989. The system developed from this program has three major subsystems:

- Navigation / route guidance,
- Traffic information providing congestion, accident and parking spaces information based on roadside beacon signals,
- Individual communication system including vehicle identification, monitoring of vehicle location and communication data such as phones and faxes.

VICS started in 1991 with more than 200 private sector companies involved. The objective was reaching better integration of the functions of AMTICS and RACS. Both AMTICS and RACS were aiming to provide traffic information to the driver, and the main difference was the technical approach used in providing the telecommunication link. The strategic plan of the VICS requires the National Police Agency, Ministry of Construction and Ministry of Post and Telecommunications to work together in order to reach the objective of the program. The program aims to inform the driver about road traffic conditions through the use of the radio communication medium. This requires the National Police Agency to expand the traffic control centers and analyze the traffic within the network, and the Ministry of Construction to operate a system of roadside communication. The two government agencies operate parallel systems for supplying data to vehicles by a wide area broadcast system (such as FM sideband). A central information collection center receives the information, and interprets and displays it at specific locations on the roads and by FM radio. In June 1993, a demo of the system began in Tokyo, and in November 1993, 500 people had taken part in the demo, which used 45 vehicles. VICS has set standards on the future use of mobile communications in Japan covering digital cellular radio, and FM sub-carrier broadcasting.

SSVS was started in 1990 to promote the R&D of ITS technologies for the next 20 – 30 years. The program was particularly interested in highway safety, and addressed analysis of the characteristics of in-vehicle systems based on technological capabilities, human factors, user requirements, technical, social and economical issues about the development and implementation of ITS, and policies concerning R&D. Objectives of these systems included allowing the driver to monitor driving conditions and receive broadcast data, and providing emergency alerts to the driver. Six areas under this program were:

- Intelligent intersection,
- Intelligent physical transportation,
- Intelligent environment recognition,
- Active driver assistance,
- Ultraminicar,
- Cooperative driving systems.

Another program, Universal Traffic Management System (UTMS), was initiated by the Japanese central government in 1971. The objectives were similar, including development of new traffic control systems with information systems, route guidance, public transport systems and pollution monitoring and advisory systems.

Commercialization of ITS has started early in Japan, and Japan was first to offer navigation systems as a part of in-car options. According to 1997 data (ref. 4), 12,000 vehicles per month were sold equipped with navigation systems at approximately US\$3000 per unit. The Japanese market for the navigation system was one-half million units plus 10,000 split between the U.S. and Europe. In the U.S. market, the majority of these units were installed in commercial vehicles and rental cars.

2.2.3 The U.S. Initiatives

A 1986 traffic study of 29 major U.S. cities estimated that \$24 billion a year was lost in those cities because of traffic congestion (ref. 4). In the U.S., more than 41,000 fatalities occur in crashes per year (ref. 5), and 5 million people are injured at a total cost of \$70 billion (ref. 4). Driver error is the primary cause in 90% of these accidents, involving passenger vehicles, trucks, and buses (ref. 5). To improve this situation, in 1991, the U.S. launched a program initiative entitled Intelligent Vehicle – Highway Systems (IVHS) with an initial budget of \$660 million, and establishment of IVHS America (ref. 4).

IVHS America was a Federal Advisory Committee, including various levels of government, private sector, academic institutions, and transport organizations. The main role of IVHS America was to identify the most appropriate technologies and strategies for the future development of IVHS (During late 1994, the IVHS board changed its name to Intelligent Transportation Society of America (ITSA)). The ITS program is a federally funded R&D program with a greater proportion of the funding coming from the private sector. It was seen as one of the outcomes of the U.S. Congressional Act passed in December 1991 (the Intermodal Surface Transportation Efficiency Act (ISTEA)). This act allowed for the allocation of \$660 million, from 1992 to 1997, to relieve congestion and improve safety on the road. The objectives of the ITS program are to use innovation and technology to fulfill national transportation goals of safety and efficiency, and to meet the transportation needs of the future. There are six areas of interest identified in the strategic plan (ref. 4):

- Advanced travel and traffic management systems,
- Electronic payment systems,
- Emergency management systems,
- Advanced vehicle safety systems,
- Commercial vehicle operations, and
- Advanced public transportation systems.

The program is administered through the federal Department of Transportation (DOT), but much of its definition, direction and review are provided by ITSA. ITSA fulfills a public / private partnership role by giving memberships to private sector companies (50% of all members), and academia, government and associations (the other 50%) (ref. 1). It helps its members to participate in on-going research, planning, standards development, and marketing of ITS programs, products, and services. It helps standards development on settings, telecommunications, safety, legal and institutional issues. It fosters international cooperation, as it is in touch with sister associations in Europe, Asia, Canada, and Australia.

In 1998, the Intelligent Vehicle Initiative (IVI) became a segment of the DOT ITS program (ref. 6). Its focal points are investigating the safety impact of combining multiple systems such as route guidance and navigation, adaptive cruise control, cellular phones, and in-vehicle computers, and facilitating the development of driver assistance safety products. IVI systems are primarily developed by the private sector. The U.S. DOT works cooperatively with industry to define performance specifications.

Development and usage of ITS in the U.S. are growing dramatically. The U.S. Transportation Secretary proposed the following IVI goals in July 19, 2000, asking industry to work with them (ref. 7): 10% of the new light vehicles sold by 2010, and 25% of new commercial vehicles sold by 2010 should be equipped with one or more IVI systems. The national goal is reducing the crash fatalities by 20% over the next 10 years. According to a new study published by Telematics Research Group, in-vehicle information systems is in the infancy stage and is on the start of an explosive growth cycle in the U.S. While only 5% of new cars sold include these systems today, by 2006 33% of new cars sold will have them, exceeding the expectations (ref. 8). Based on another study, the world market for personal vehicles will rise from the current level of \$3 billion to almost \$13 billion by 2006, with recurring annual service revenue accounting for over \$4 billion of the \$13 billion total (ref. 9). According to new analysis by Frost & Sullivan, North American Automotive Telematics Market, the total market rose from \$60 million in 1999 to \$380 million in 2000. Double-digit growth could bring this market to \$7 billion in 2007 (ref. 10).

2.3 Summary of ITS Historical Development

Table 1 includes a comparative summary of historical development of ITS programs in Europe, Japan, and U.S.A., based on the discussions so far. Japan is the first country that officially started working on ITS projects in 1971. The European Union follows Japan by starting formal research in 1986, and studies in the U.S. are relatively new, starting in 1991. In all countries, ITS programs were launched as a result of traffic problems such as urban congestion, increased cost from time devoted to traveling, accidents, rising road deaths, safety, security, and environmental pollution. Driver errors are one of the primary causes of accidents, and new on-board transportation systems including integration of electronics, computers and telecommunications are expected to reduce these problems. Start dates of these programs are not close. The reason for that could be due to different traffic needs in these countries at different times.

Another similarity of these programs is the cooperation between the public and private sectors. The public sector usually initiates, supports, and leads the ITS studies while private sector contributes to the funding, R&D projects, and applications. Objectives of these programs are also similar: Providing on-board route guidance and navigation, fleet management, traffic and travel information (such as road works, parking, location of major facilities, emergency information of weather conditions, pollution monitoring and advisory systems) through various communication systems (such as cellular phones, and in-vehicle computers), and facilitating the development of driver assistance safety products.

The use of ITS is rising dramatically in the countries mentioned above, while an increasing number of users prefer vehicles equipped with on-board information systems. According to a 1998 study, usage of these systems in Japan, Europe, and Australia has been greatly accelerated through mutual cooperation of the public and private sectors.

This section has provided general information on ITS in different countries, including historical developments and similarities between them in terms of reasons to start these studies and their applications. The rest of this report focuses primarily on ITS in the United States, beginning with the next section that briefly discusses technical issues in ITS deployment.

Table 1. Comparative summary of historical development of ITS in Europe, Japan, and U.S.A.

Timeframe	Europe	Japan	U.S.A.
1971	-	* The government initiates UTMS. The objective is having fully operational ITS in late 1996 or early 1997.	-
1980s	-	* Japanese ITS initiative is formed.	-
1986	* A research program, PROMETHEUS is formed.	* Continuing research	-
1987	* European Union supported EUREKA project is initiated.	* AMTICS is launched. * RACS tests are started.	-
1988	* Launch phase of EUREKA. * A parallel program, DRIVE is adopted by EU.	* AMTICS pilot tests are started in Tokyo.	-
1989	* Research phase of EUREKA. Annual funding is \$113 M, 2/3 by industry and 1/3 by ministries. * CEDs are formed. Integration of military and aircraft technologies into land transport.	* RACS tests are ended. * AMTICS pilot tests are being carried out in Tokyo.	-
1990	* Continuing research	* SSVS is started to promote R&D of ITS technologies for the next 20 – 30 years. * AMTICS pilot tests are ended.	-
1991	* ERTICO is formed.	* VICS is started. The objective is the integration of AMTICS and RACS.	* IHVS is formed.
1992	* Continuing research	* Continuing research	* 1992 – 1997: ISTEA allowed for the allocation of \$660 M in order to relieve congestion and improve safety on the road.
1993	* Continuing research	* A demo of VICS began in Tokyo. VICS set standards of future use of mobile communications in Japan.	* Continuing research
1994	* PROMETHEUS and DRIVE are concluded.	* Continuing research	* IHVS became ITSA. * The first detailed program definition is published.
1995	* Continuing research	* Continuing research	* Continuing research
1996	* Continuing research	* Continuing research	* Continuing research
1997	* Other programs such as the 4 th FRAMEWORK are in progress.	* 12,000 vehicles / month are sold equipped with navigation systems at \$3000 / unit. The Japanese market for navigation systems is one-half million units.	* Refer to year 1992.
1998	* The use of ITS is accelerated.	* The use of ITS is accelerated.	* IVI became a segment of the DOT ITS program.
Forecasts from 1998	N/A	N/A	* The investment estimate in ITS from 1998 to 2011: \$209 B. * The number of users estimated by 2005: 5 M. * The estimate of the amount spent by users on hardware by 2005: \$1.4 B. * The estimate of the amount spent by users on services by 2005: \$1.2 B.

2.4 Technical Issues in Intelligent Transportation Systems Deployment

A key goal for organizations such as Intelligent Transportation Society of America (ITSA) is the development of nationally compatible systems that will improve inter-city travel and cross-country goods movement while maintaining compatibility and service standards. For example, the program's national architecture and technical standards define the ITS elements and the way they will work together, and they are a prerequisite to a large-scale, integrated system deployment.

There are constructive results of architecture development. The definition of an architecture leads to development of system interface standards and protocols, and reduces risk to those responsible for providing ITS infrastructure or investing in the development of ITS products and services. For example, the development of architecture will help resolve issues such as whether optimal routings are calculated by in-vehicle computers using information transmitted to the vehicle or calculated at traffic management centers and then transmitted to vehicles. This single issue has major implications on the costs of in-vehicle equipment (and, therefore, affordability), the costs of providing and maintaining public infrastructure, and which communications technologies can be accommodated. A summary of the various Standards Developing Organizations (SDO) that are concerned with developing ITS standards for mobile communication applications is presented in Table 2 (ref. 11).

On the other hand, the level of federal involvement in this standardization process is also a topic of discussion. The main issue is that while a large-scale federal deployment (standardization) program would be necessary to achieve widespread deployment, this would have the drawback that it would limit local flexibility and would increase the cost of regulation and compliance.

The next chapter discusses the current ITS products and technologies that are employed in the market place.

Table 2. Standards Developing Organizations and Activities

SDO (Standard Developing Organization)	ITS Standards Topics Addressed	Standards Activities
ASTM (American Society for Testing and Materials)	Vehicles-to-roadside communications, traffic and application device interconnection protocol, smart materials and systems	<ul style="list-style-type: none"> • Systems with User Requirements and Test Method • Practice for Highway Traffic Monitoring • Practice for Dedicated, Short Range, Two-way Vehicle-to-Roadside Communications Equipment • Specification for Data Formats from Traffic Data Collection Equipment
EIA (Electronics Industries Association)	R-3, audio systems and R-4, video systems	<ul style="list-style-type: none"> • Radio Broadcast Data System • High Speed FM Subcarrier • Digital Audio Radio • National Data Broadcasting Committee
IEEE (The Institute of Electrical and Electronics Engineers)	Communications, electrical and software safety and other topics within the field of electrotechnology	<ul style="list-style-type: none"> • Vehicle Radar • Lightning Protection for ITS Applications • Dictionary and glossary of ITS terms • Standard protocols and message sets for vehicle
ION (Institute of Navigation Systems)	Navigation systems	<ul style="list-style-type: none"> • Recommended practice for Benchmarking the Positioning Performance of a Navigation Systems
ITE (Institute of Transportation Engineers)	Equipment and Material Standards	<ul style="list-style-type: none"> • Standard Vehicle Detectors
TIA (Telecommunications Industry Association)	Communication protocols	<ul style="list-style-type: none"> • National Tele-communications IVHS Protocol • Software protocols for in-vehicle communications
SAE (Society of Automotive Engineers)		<p>Recommended practices:</p> <ul style="list-style-type: none"> • Interface between an on-board computer and a communication device • Navigation Message Set • On-board Land Vehicle Positioning Device • In-Vehicle Sensor Interface for ITS Applications • Traveler Information Service Message List

3 Automobile and Trucking Industry Products

A broad range of the automobile and trucking (A/T) industry currently employs ITS. Examination of these systems may result in identification of certain technologies and applications that can be used in General Aviation (GA). For this reason, this chapter and chapter 4 introduce current products and technologies in the A/T industry. As a starting point, chapter 3 focuses on ITS in the A/T industry, in order to identify product and market parallels that provide insight on acceptance of cockpit information systems by the GA market. Chapter 4 examines the enabling technologies behind these products.

The information in this chapter was developed from a literature search and user interviews. The chapter subsections include interface technologies in ITS products in the A/T industry, various product services, typical costs, lists of current products and their features, and future developments.

3.1 Interface Technologies

The device interface conveys the information to the user through a number of communication mediums such as voice, text, visual and audio cues, and graphics. The primary concern is with the portrayal of the information and the method of interaction with the user. This section starts with general information on In-Vehicle Information Systems (IVIS). Then, selected display technologies such as Liquid Crystal Displays (LCD), organic LED (Light Emitting Diode) displays, and night-vision and head-up displays (HUD) are described. After that, based on the information provided, user interfaces are discussed, and finally product services are examined in brief.

3.1.1 In-Vehicle Information Systems (IVIS)

A fundamental design choice for an in-vehicle information system is whether to locate the computing in the car or in a remote server. In the remote server case, communication with the car occurs only while the remote server receives information from other sources, and processes the request based on this and the information in its database. In this case, updating the map database, upgrading software or adding new services does not require changes in the vehicle.

Navigation and route guidance systems are the most common in-vehicle information systems in use today. The information presented by most navigation systems includes turn-by-turn directions, dynamic route calculation based on current location, and turn restrictions and speed limits. GPS signals are combined with map information stored on CD-ROM to display the position and direction of the vehicle. Most navigation systems also include an electronic gyro-sensor and a speed sensor that enable it to display the present vehicle position even in locations where GPS signals may be blocked. The user can instruct the system to calculate the route based on the following criteria: shortest route, maximize freeways, minimize freeways, minimize toll roads.

Current IVIS (In-Vehicle Information Systems will be referred to as on-board information systems, or briefly IVIS for the rest of this report) products do not utilize a large amount of real time data except for location, but this is rapidly changing. For fixed services or services that are specific to a particular area, static information databases can be used, which inform the traveler of key locations of interest such as food, lodging, service and gas stations. Bandwidth suffers when the receiver is in motion, limiting the amount of data deliverable to a moving car. One concept is that when filling up with fuel at a gas station or convenience store, the vehicle could also fill up with information using a short-range wireless protocol.

3.1.2 Display Technology

One of the functions of In-Vehicle Information Systems (IVIS) (see section 3.1.3) is to manage and fuse all driving-related information from a variety of sources. For example, IVIS integrate information from roadway signs, traffic conditions, and other sources for presentation to the driver. Information filter functions assure that the only messages displayed are those that are important to the driver and which apply. Display functions optimize the presentation of the message to ambient conditions, driver preferences, the number of simultaneous messages, the urgency of the current message (prioritization), and signal timing, i.e. when the message will be activated and will be deactivated. The selection of display modality (i.e. audio or visual) and type of display (e.g. head up), as well as design of display formats are issues that are faced by designers of IVIS.

The latest dash mounted displays in luxury cars have multi-function displays that integrate common controls, vehicle diagnostics and digitized maps for navigation. Most communication and information devices make use of monochromatic or color displays to display a variety of texts, symbols and graphics. Developments in technology have resulted in displays becoming thinner with better resolution and less power consumption.

3.1.2.1 Liquid Crystal Display (LCD)

LCD is the foremost display technology in use today and has increased from VGA resolution (640x480) and SVGA resolution (800x600) to XGA resolution (1024x768). LCDs available today have visual quality as good as that of a CRT (cathode ray tube). The original LCDs were based on Super Twisted Nematic (STN) technology, which progressed into dual-scan STN (DSTN). DSTN displays divide the screen in half, with each half being scanned simultaneously, thereby doubling the number of lines that are refreshed per second and creating an image that comes closer to the quality seen on CRTs. More refined versions of DSTN, such as High Performance Addressing (HPA), are making the DSTN displays better. The current state-of-the-art in display technology is the active matrix Thin Film Transistor (TFT) technology. Active matrix LCDs address each pixel on the display individually and provide a higher refresh rate than DSTN, creating clearer images with higher contrast and more vibrant colors. TFT displays have an active-matrix backplane that puts a thin-film transistor behind every pixel.

The latest Super XGA + TFT screens support extra high resolutions of up to 1400x1050 pixels. While dual scan displays are still being used quite a lot, the recent closing of the price differential between DSTN and TFT displays indicates that it is likely that DSTN will be used on fewer systems in the coming years.

The greatest drawback of LCDs is that they are expensive and, for example, may account for as much as a third of the cost of a laptop. The failure to reduce the price of portables as dramatically as the price of personal computers has been due largely to the inability to decrease the cost of the display-screen. The complex and difficult manufacturing process of the LCDs is the reason for this, especially when it comes to high-end versions used in color displays.

3.1.2.2 Organic LED Display

A radically different technology, called organic light-emitting diodes, is a possible alternative to LCDs. This device resulted from the discovery that, when charged by electrodes, certain organic materials emit their own light, and have the ability to exhibit ultrabright colors and process high-clarity video images. The ability to display video comes from the property that they can be switched on and off

quickly, which is crucial for video, where images are updated 50 or 60 times a second and get blurred if the screen cannot keep up.

One of the drawbacks of LCD technology has been the inability to view the display at all angles, and this remains a problem today. Organic LEDs may address this problem since they look equally bright from all angles. The most significant advantage over LCDs is that they have much simpler and thus cheaper manufacturing process. Their structure in principal is an electrode, some organic material, and another electrode. When a voltage is applied, light is produced without any need for backlight, diffuser or polarizer as in the LCDs. They also have far lower power consumption than LCDs since LCDs need backlights to be visible in daylight and this is a major drain on the portable's batteries. The organic LEDs are beginning to appear in some of the new released models of cellular phones and will eventually have a significant market share in the coming years.

3.1.2.3 Night-Vision and Head-Up Display Technology

With the advent of in-vehicle information systems, the driver has a multitude of information being presented, usually on a LCD panel mounted in the center console. This requires the driver to momentarily glance away from the road to scan the information presented. For example, with in-vehicle navigation systems, the driver may be required to scan route guidance information, such as the distance to the destination. As a solution to this, Head-Up Displays (HUD) are being developed that display the vehicle controls as well as navigation information in order that the driver does not avert his eyes from the road.

In automobiles, HUD information is projected onto the windshield through a projection device called a Fresnel Lens (Stokes). Typically, the HUD information is optically conveyed to appear to be virtually 1.5 to 6 meters away from the driver. Thus, if a car were equipped with a HUD that displayed the vehicle speed on the windshield, it would appear as if the speed were floating in space 1.5 to 6 meters outside the front windshield. Such exotic technology that was once only in the realm of fighter aircraft can now be standard equipment in the high-end Pontiac models. These cars contain the EyeCue system, which displays a digital representation of vehicle speed, the current radio station, and the status of the directionals in a HUD. In addition, some Cadillac models are equipped with a HUD-based night vision system. With this system, an infrared picture of the road ahead is presented on the windshield to aid in night driving.

The minimal amount of information should be presented on a HUD so as not to obscure the view out of the windshield. Due to the unproven cognitive issues and factors related to the interference with the driver's view of the external environment associated with the use of HUDs, the deployment of HUDs in automotive information systems has been negligible and the technology is still in the trial stage.

3.1.3 Speech Recognition Technology

Speech recognition is the ability for a device to recognize individual words or phrases from human speech. These words can be used to command the operation of a system (computer menus, voice-activated controls or direct input of speech into an application). This technology is becoming very important in the vehicular industry, because of its ability to reduce distraction, and increase driver safety. For example, speech recognition technology allows motorists to instruct a navigation system where they want to go and then listen to the system tell them turn-by-turn directions using actual street names and named places. Applications are being developed that control the vehicle's electronic systems such as temperature, lights, door lock and sound through voice commands. On-board speech recognition has already been deployed in high-end model of Jaguar, General Motors and Daimler-Chrysler to access radios, CD players and navigation systems.

Important for the satisfactory operation of a good speech recognition system is the noise suppression and noise cancellation techniques that prevent the ambient noise from blanketing the actual speech. Vehicles, unlike desktop PCs, are subjected to a wide variety of noises that can confuse software-based speech recognizers. There are numerous noise sources including the road, wind, defroster, fan, radio, windshield wipers and backseat occupants. Another factor that affects the sensitive speech processing hardware is the electrical noise introduced by other car electronic systems that share the power supply with on-board speech recognizers, for example, air-conditioners. Compounding the problem is that in-vehicle speech recognition is often done by remote servers over cellular links. Speech recognition over a cellular link is technically challenging as the system deals with more than just the noise generated by the vehicle.

A technique used to increase the accuracy of the speech recognition is for the processor to map the particular signal characteristics or frequency spectrum of the user's voice through a set of training data. This information can then be used to extract the signal from surrounding noise by selectively canceling out all other interference except the known signals of interest. However, even though there are noise cancellation techniques available, these mostly work for steady-state noise and random and fluctuating noise sources such as children in the back seat, windows opening and closing, and mechanical noises in the cabin cause problems. Automakers are concerned about even the subtlest lack of accuracy because it could place greater "cognitive load" on the driver, who theoretically should be free to concentrate on traffic and driving conditions (ref. 12).

Despite these problems, speech recognition is being extensively promoted because it is considered as an essential component to the successful implementation of safe and practical in-vehicle information and communication systems.

3.1.4 User Interfaces

Telematics (see section 2.1) developers still debate the interface for in-vehicle information systems (voice, screen, or some combination plus ways to decrease the 'cognitive load'). One method of determining the attention required of a particular device interaction is to list the steps that need to be performed to get the desired result. Generally, this consists of the time it takes to enter the input, and the time to mentally process the auditory or visual information, by assigning a 'visual task time' to the whole operation.

Enhanced user interfaces can be developed that 'learn' the frequent functions accessed by the user or the pattern of use, and subsequently re-configure the display to make those functions most easily accessible or visible to the user.

Since the costs of having a large LCD panel in the dashboard can be prohibitive for most users, several automakers are offering a system that can work with existing hardware. For example, Siemens Automotive plans to borrow a display, storage, and processing power, from a Palm Pilot or other handheld device that would slip into a docking cradle. That would not only hold down costs but also provide in-vehicle access to electronic address books, phone lists and schedules. It would also offer more seamless connection between the car and the rest of the driver's life since whatever was downloaded in the vehicle could be carried outside, and vice versa. When the car is started, the following four choices appear on the Palm's screen: Navigation, Traffic, News, and Messages.

3.2 Services

Various in-vehicle information products offer advanced features and value added services such as text messaging, concierge, traveler information, weather information, vehicle operation reports, maintenance alerts/ reminders and rideshare information. The latest in-vehicle "driver information systems" devices such as in-dash units or pen-based handhelds are equipped with on-board computing systems, routing and reporting software, and Global Positioning Systems (GPS). The menu of advanced travel information services slated for future in-vehicle information systems will include real-time congestion reports, travel incidents by location, road maintenance sites, parking availability, transit bus and train schedules and routes, schedule of public events, and electronic yellow pages information. Some of these services such as traffic information will be available from state or federal transportation authorities through various broadcast or two way microwave or RF links and also privately through the internet or private service providers for a subscription.

3.3 Product and Service Costs

In-Vehicle Information System (IVIS) costs are generally divided into device and installation costs, and service fees. These are also referred as non-recurring and recurring costs respectively. In this section, typical costs are discussed for automotive and trucking Industries separately.

Based on an interview with a carrier company that has a fleet of trucks, an information system provider charges \$1,700 as the non-recurring cost for its in-vehicle system that provides services particularly for the trucking industry. It is a cellular-based on-board system with two-way text and voice communication, and a separate GPS. It also has a separate display, and it can be integrated with PC-based systems if required. This system has other services such as emergency signal to the dispatcher. The information system provider charges 50 cents per message (the recurring cost), and this costs the carrier company approximately \$55 per truck per month. Since this information was not obtained by publicly accessible sources, company names are kept confidential. Based on the literature search on information system costs in the trucking industry, these are typical costs for a typical In-Vehicle Information System.

System costs in the automotive industry differs from the costs in the trucking industry. This is often due to the fact that the information system costs are included in the total price of the car. Therefore, there are often no non-recurring costs, but the recurring costs still exist. For example, in 2001 models of Mercedes-Benz, there is a system called COMAND, integrated into the front panel. Communication is through text messages, and there is a push-button system that allows the driver to access her/his web page as well. The web page should be previously personalized by the driver within the Mercedes-Benz USA web site at www.mbusa.com. These web-based information services are provided by another company: CNN Interactive. It may contain information on stocks, weather, sports, news topics, etc., according to the driver's personal interests. This service does not require a non-recurring cost additional to the price of the car, but an annual recurring cost is required, which is \$125 plus airtime.

While the previous paragraph is an example of IVIS, integrated into the front panel in automobiles, there are also a number of portable systems such as the Scout Electromedia - Modo. This is a satellite based, portable system, including information about restaurants, shopping, hotels, and other attractions in three major cities: New York, Los Angeles, and San Francisco. This information is updated daily without any charge. There are no recurring costs for this system, while the non-recurring cost is \$99. Similar information about other cities will be added to the system in the near future.

This section included typical costs of IVIS in automotive and trucking Industries. The following sections summarize information system products currently in use in these industries and their features, and investigate future developments, by addressing product names, system providers, and manufacturers.

3.4 Summary of Products Used in Automotive and Trucking Industry and Their Features

A market search on current on-board information systems in both automotive and trucking Industries was developed by using primarily Internet sources such as company web sites, magazines, and the ITSA web site (ref. 1).

According to this market search, in the trucking industry, the communication method is generally either satellite, cellular, or radio. There are also separate or integrated GPS systems on-board. Text messages are common for communication between the driver and the dispatcher. Displays are usually either separate, or integrated into the front panel or a laptop. Data entry is performed by either using a touch screen display, voice by cell phone, or a keyboard. There are a large amount of services provided to the trucking industry such as maintenance and performance monitoring to the driver, emergency alert, automatic location information to the dispatcher, configurable business forms and templates, optional printer, fax, pager, special function buttons, and black box.

In the automotive industry, the communication method is usually cellular based. Communication is often provided by either text, or voice messages (by cell phone), or both, generally by communicating with an assistance center, which provides most of the information that the driver needs. For navigation, integrated or separate GPS devices are provided. Data entry to the system is usually by using special function buttons. For example, in the General Motors OnStar system, there is a three-button communication system, one button for emergency assistance, one for answering a call from the OnStar Center, and another one for connecting to the OnStar Center. System services can be grouped as maintenance and performance monitoring, roadside assistance, and other services. Automatic airbag deployment notification to the assistance center is an example of maintenance and performance monitoring service. Roadside assistance provides information about the road ahead such as traffic updates and weather information to the driver, and emergency location information to the assistance center. Stolen vehicle tracking, satellite radio subscriptions, driver medical data storage, and e-commerce are some of the other services.

A comparative summary of current products used in trucking industry, including selected system providers and product descriptions is provided in Table 3. Another comparative summary of current products used in automotive industry, including selected automotive companies and system providers with product descriptions is provided in Table 4. In both markets, information system products are divided in three categories: interface, display, and services. The next section examines future developments on some of these products.

Table 3. Summary of Selected Current Trucking Industry In-Vehicle Information Systems

System Provider	Product	Interface			Display		Services
		Communication Method	Messaging	Navigation	Screen Location	Data Entry	
QUALCOMM – OmniTRACS Div.	OmniTRACS	Satellite	Text (2-way) and Graph	- Qualcomm Automatic Satellite Position Reporting (by satellite triangulation), or - Integrated GPS	Separate	Integrated keyboard	- Maintenance and performance monitoring - Panic button
Track Communications, Inc.	Highway Master	Cellular	Text and Voice, 2-way	Separate GPS	Separate	Voice by cell phone	- Capability of integration with PC-based, Unix, AS/400 systems - Time of arrival is calculated - Alert to dispatcher
EATON Trucking Information Systems Div.	Fleet Advisor	Satellite or Radio	Text, 2-way, limited from driver	Separate, or integrated GPS	Separate	Touch screen	Maintenance and performance programming
TruckScribers	T-Scribe 2000/3000	Cellular (direct telephone modem, or Internet)	Text, 2-way, limited from driver	Integrated moving map GPS	Integrated, or lap top	Mouse, or keyboard	- Maintenance and performance monitoring - Black box
TERION	Mobile Messenger / Workstation	Radio	Text, 2-way	Separate GPS	Separate	Integrated keyboard	- Emergency message button - Location sent automatically if necessary - Configurable forms and templates

¹ Other Services: Special function buttons, printer, fax, pager.

Table 4. Summary of Selected Current Automobile Industry In-Vehicle Information Systems

Automotive Company and System Provider	Product	Interface			Display	Services		
		Communication Method	Messaging / Data Entry	Navigation		Maintenance & Performance Monitoring	Roadside Assistance	Others
General Motors	OnStar	- Based on GPS and cellular technologies - 3 – button communication - Voice communication oriented with advisors in OnStar Center	- Voice communication ¹	In-vehicle GPS receiver calculates location constantly	- No screen. 3-button communication ¹ : 1. Emergency Assistance 2. Answer a call from OnStar Center 3. Connect OnStar Center	- Automatic airbag deployment notification to OnStar Ctr. - Remote door unlock	- OnStar button sends vehicle location to the center - Advisor assistance	- Stolen vehicle tracking - Accident assistance - Driver medical data storage
Ford and QUALCOMM ² (Ford is also partnering with Sprint PCS)	Wingcast	- Probably cellular - Limited services will start in 2002 in a million vehicles - By 2004, every vehicle will have these systems	Voice recognition	Probably GPS	- Portable, useable outside as well - Hands free email	Safety and security features	Real time traffic updates	- E-commerce - Satellite radio subscriptions
Mercedes (HW/SW from Motorola, emergency response service from Protection One)	TeleAid	- Based on GPS and cellular technology - 3-button communication - Voice communication oriented with 3 different centers	Voice communication	Same as in OnStar	No screen. 3-button communication: 1. Emergency Assistance from Protection One Ctr. 2. Contact Mercedes-Benz Roadside Assistance Ctr. 3. Contact Client Assistance Ctr.	Automatic airbag deployment notification to Protection One Ctr.	Same as in OnStar (Mercedes-Benz Roadside Assistance Ctr.)	Same as in OnStar

¹ See Section 3.5.

² This is a future system, but it is worth to be compared to others since this information is already provided by the manufacturer.

3.5 Future Developments on Existing Products

This section examines future developments that are being planned by the information systems providers for the trucking industry, and by the automotive companies that partner with system providers. This information is derived from Internet sources such as company web sites, ITSA newsletters, magazines, press releases, and a number of interviews with system provider companies. The dates provided in this section and in upcoming sections are subject to change according to the development levels of the products at the time this report is submitted. Some of the following information may actually exist on the submittal date due to rapid development in this market, while some of it may be delayed.

Information system providers in the trucking industry are considering the following key developments areas for their products in the future:

- Internet access on-board
- Traffic information services integrated with route optimization
- Increased capacity and baud rates
- Voice recognition

Systems used in the trucking industry are provided primarily by information system companies, while automotive companies often prefer to build partnerships with information system providers for their products including on-board information systems. For example, Ford partners with Qualcomm, which is an information system provider for the trucking industry as well (see Table 3). This partnership resulted in the Wingcast system. Similarly, Mercedes obtains hardware and software from Motorola, and emergency response service from Protection One, for its TeleAid system. Some of the future developments being considered in the automotive industry are described below:

General Motors – OnStar Messaging / Data Entry Future Developments (in 2001): Hands Free Voice Communication:

- Integrated into the front panel.
- Voice recognition for phoning, as well as for other communications with Virtual Advisor (through certain predefined commands).

General Motors – OnStar Display Future Developments (in 2001): Virtual Advisor:

- Internet access through Virtual Advisor: A previously customized web page is needed. Virtual Advisor downloads it and relays it to the driver via speech recognition technology.
- Personalized information on the web page: email, stocks, sports, news, and weather.
- Weather: There is additional weather information via a touch button. Current forecast, or alert conditions are provided.

Motorola – Jaguar (all Jaguars in 2001): Timeport wireless phone and communications system.

- Access to Internet content on the system's microbrowser, traffic, maps, weather, news, and other information.

Delphi Automotive Systems (in December 2000): Installation of Mobile Productivity Centers to any vehicle.

- A docking station for a PDA or a cell phone.
- Enables downloading emails, responding by voice commands, and uploading phone numbers and addresses.

The previous chapters have provided a base on current on-board information systems, their features and developments. Chapter 4 discusses selected enabling communications technologies that supported present systems and will provide a basis for future products.

4 Enabling Communications Technologies

This chapter examines enabling communication technologies such as wireless data networks, and device technologies for wireless connectivity. These technologies are selected according to their possible application in GA cockpit information systems, and their growing demand potential, considering their characteristics today and developments in the future.

4.1 Wireless Data Networks

The developments in mobile communication systems are supporting a progression from voice only networks to networks providing broadband multimedia services to meet the diverse information and communication requirements of the mobile community. Data transmission is important because it represents an accurate and efficient means of communication. Initially, voice band modems were able to transmit data over first generation analog radio networks with speeds of up to 300 bps. With advances in technology, data transmission over first-generation analog cellular networks is now able to achieve speeds up to 14.4 kbps. With the first-generation analog networks, data transmission was only an option. However, second and third generation digital cellular radio networks have data communication capability as a standard feature. The timeline shown below maps the advent of mobile data:

- 1890's - Marconi's first radio transmission
- 1920's - First pagers (non-commercial use)
- 1940's - AT&T Mobile Telephone Service (MTS)
- 1960's - Improved MTS
- 1970's - First generation cellular (e.g. AMPS)
- 1980's - Commercial-use pagers
- 1990's - Low to Medium-speed wireless data
 - CDPD (19 kbps), 2G digital cellular (9.6 kbps), 1G wireless LAN (2-4 Mbps).
- 2000's - Medium to high-speed wireless data
 - 2.5G digital cellular (< 384 kbps), 3G digital cellular (< 2 Mbps), 2G wireless LAN (10-155 Mbps), Bluetooth 2 (10-20 Mbps), HomeRF (10-20 Mbps), Wireless Cable (10-100 Mbps).

Data can not only transmit more information in a given time than voice, but also provides means for documentation, such as dispatch centers recording fleet tracking and driver messages. The number of applications for mobile data are growing and aside from traditional users such as courier companies, taxi dispatches, and transportation companies for fleet management, it is gaining a wider consumer base. One of the major application areas is in information or data base retrieval. This is particularly useful when access to specific records is required, such as in the medical field where ambulances can access patients' records and prepare the hospital for the emergency. Also police vehicles armed with data capability are able to look up vehicle registration details or criminal records, and field personnel may retrieve pricing information. The data rate requirements for a variety of wireless and wireline services are included in Table 5 for comparison.

Table 5. Bit Rate Requirements for Common User Applications

Application	Representative Rate (kilobits/second)
V34 Modem over Telephone Voice Circuit	33
Inter-office Digital Telephone Voice Circuit	64
Low-resolution Conference-Quality Video (compressed)	200
Compact Disc Audio	1,400
VCR Quality TV (compressed)	1,500
Broadcast Quality TV (compressed)	5,000
High Definition TV (compressed)	20,000

This section examines four categories of wireless data networks: Private mobile networks, Multichannel multipoint distribution services, Satellite networks, and Third generation cellular. These networks provide different ways to communicate information between the nodes of a communication system over a wireless channel. Networks that support data will be studied since these are the only ones that have the capability to provide multimedia services such as graphics, text as well as voice.

There are two types of wireless networks: local area networks (LANs) and wide area networks (WANs). Local-area wireless data networks, which are typically employed as private systems in businesses, corporate and university campuses provide wireless data service in a small geographical area. For this reason, they do not experience the same rough physical layer constraints such as fading, multipath and interference experienced by their wide-area counterparts. Therefore, they are capable of supporting high-speed wireless data transmission, on the order of a few Mb/s. However, of more interest are WANs, which will be the focus of this report, as they are meant for applications requiring mobility, and long distance connectivity.

Along with data transmission over analog radio and cellular networks, mobile data-only networks are available. These are developed with proprietary modems and access techniques and use packet switching to transport data rather than circuit switching, which is typically used in cellular or cordless networks. These networks are the Private Mobile Radio Networks, described in this section, and they continue to expand their coverage to more urban areas and will remain the method of choice for many specialized applications. However for widespread personal use, they will continue to face competition from data over cellular standards, especially the third generation ones being developed such as EDGE (Enhanced Data Rate for GSM Evolution) and GPRS (General Packet Data Service) (see Section 4.1.4). There are a number of wireless WANs available from different network infrastructure suppliers for private installation, or network service providers for public shared use. Private mobile radio networks, MMDS, Satellite Data Networks, and Third Generation Cellular Networks are discussed in the following sections.

4.1.1 Private Mobile Radio Networks

Motient and BellSouth Mobitex Network are described below, as subgroups of Private Mobile Radio Networks.

4.1.1.1 Motient

Formerly known as Advanced Radio Data Integrated System (ARDIS), this was the first two-way nationwide data network of its kind in the U.S. It utilizes radio packet technology of the DataTAC network and has upgrading to the Motorola's RD-LAP technology. DataTAC is a communications standard that provides an infrastructure for wireless data communications used in 9 countries (US,

Canada, Australia, Germany, Switzerland, Singapore, Thailand, Hong Kong and Malaysia). It was originally created and jointly owned by Motorola and IBM to serve IBM field technicians. In 1995, Motorola acquired 100% ownership of ARDIS, and ARDIS was acquired by the American Mobile Satellite Corporation in 1998. ARDIS is quoted as covering 90% of the urban business population and more than 400 metropolitan areas in the United States, Puerto Rico, and the Virgin Islands with an estimated 40,000 users (ref. 13). The mobile communication device is the RIM wireless handheld that features wireless data service and the eLink wireless e-mail that is always connected to receive e-mail without having to dial up. The satellite service provides the extended coverage and is used in the MobileMAX product of Motient, which combines land-based and satellite technology to provide data messaging, asset and freight tracking and fleet management capabilities.

Motorola has developed two proprietary air-interface protocols for the ARDIS packet network: the MDC-4800, which provides up to 4,800 b/s service, and the RD-LAP, which provides up to 19,200 b/s service. MDC-4800 service has been deployed throughout the ARDIS network but most major service areas have now been enhanced with RD-LAP capability. The operating frequency band is 800 MHz and the RF links use separate transmits and receive frequencies, 45 MHz apart, that are simultaneously used to form a full-duplex channel. ARDIS was initially implemented with a RF channel data rate of 4800 b/s per 25 kHz channel, but it has been upgraded to 19,200 b/s in some service areas. The base station power is approximately 40 W, which provides line-of-sight coverage up to a radius of 10 to 15 miles. On the other hand, the radio terminals operate with 4 W of radiated power. The areas covered by the individual base stations overlap to increase the probability of a signal from a radio terminal reaching at least one base station. The overlapping coverage, combined with designed power levels and error-correction coding in the transmission format, insures that ARDIS can support portable communications from inside buildings, as well as outside. This capability for in-building coverage is an important characteristic of the ARDIS service (ref. 13).

Inside every cell, the radio terminals access the network by using a random method called Data Sense Multiple Access (DSMA). Before every transmission, a radio terminal listens to the base station transmitter to determine whether a "busy bit" is on or off. This bit indicates whether the base station is currently receiving data (busy bit is on) or not (busy bit is off), and it encodes the current state of the shared uplink channel (ref. 13). When this bit is on, radio terminals are prohibited from transmitting; therefore the packet collisions are avoided. On the other hand, when the busy bit is off, a radio terminal is allowed to transmit. However, if two terminals happen to begin transmission at the same time, the packets collide and retransmission is attempted (ref. 13).

4.1.1.2 BellSouth Mobitex Network

Bell South Wireless Data operates a mobile packet radio data network that provides remote access to data and two-way messaging for mobile computing applications. The technology on which this network is based is Mobitex from Ericsson. In 1999, there were public Mobitex networks in operation in at least 15 countries on four continents. Mobitex is a worldwide standard, introduced by Swedish Telecom, now called Telia Mobitel, and controlled and administered by Ericsson Mobile Communications and the Mobitex Operators Association (MOA). All Mobitex networks use the same protocols and operate under the same specifications. The MOA oversees the specifications, coordinates software and hardware development, and evolves the technology. The specifications are published by the MOA without any license or fee, thus there are many terminal suppliers and equipment developers (ref. 14). European Mobitex operators are now introducing international roaming, a service that will allow Mobitex users to continue to send and receive messages and access data outside their home countries.

In the United States, Mobitex technology was introduced by RAM Mobile Data, a company that was originally formed in 1989 as a joint business venture between BellSouth and RAM Broadcasting

Corporation. Today, RAM Mobile Data is owned by BellSouth, with a nationwide system with more than 1200 base stations installed. The service is provided in more than 7700 cities and towns, covering approximately 93% of America's urban business population, and more than 11,000 miles of interstate highway, with automatic seamless roaming across all service areas. Furthermore, additional coverage is being implemented in order to expand the service area in the near future (ref. 15).

The Mobitex system employs a cellular layout in order to provide wireless communication services to a specific geographical area. It utilizes a hierarchical structure that may contain up to six levels of network nodes, depending on the size and the area of coverage. The infrastructure comprises three types of nodes: base stations (base), local switches, and regional switches. The cells served by the same local switch form a service area or a subnet. In each service area 10 to 30 frequency pairs (called channels) are allocated to radio service (ref. 14). Each base station typically utilizes from one to four channels, depending on the anticipated cell loading. All these channels have 12.5 kHz bandwidth and support a data rate of 8 kb/s. Mobitex networks in the US generally operate at 900 MHz.

A Mobitex network can be configured in many different ways, from a large public network providing nationwide coverage to a small, privately owned network serving a single company or region and can be applied to mobile or fixed applications. Mobitex can give access to corporate resources and extend a company's fixed networks, such as query a central database or monitor and control equipment in a remote location, as well as access to the Internet. Devices such as two-way pagers, laptops and PDAs are able to access the network. The new 3Com Palm VII uses the Mobitex network for wireless e-mail.

4.1.2 Multichannel Multipoint Distribution Service (MMDS)

MMDS, also known as wireless cable, is a relatively new form of broadcasting and communications service. It enables the user to have a series of channels re-transmitted from satellites and ground stations with excellent image quality. Although this is still a relatively new form of transmission, the use of MMDS is growing significantly throughout the world.

MMDS transmitters consist of components very similar to those normally used for television bands (AM modulation), integrated with power amplification stages operating in the 2-GHz range and requiring high linearity characteristics (class "A"). It was conceived as a substitute for conventional cable television; however, it has applications in telephone/fax and data communications. In MMDS, a medium-power transmitter is located with a broadcast antenna at or near the highest topographical point in the intended coverage area. The workable radius can reach up to 70 miles in flat terrain (significantly less in hilly or mountainous areas). Each subscriber is equipped with a small antenna, along with a converter that can be placed next to, or on top of, a conventional TV set. There is a monthly fee, similar to that for satellite TV service. The MMDS frequency band has room for several dozen analog or digital video channels, along with narrowband channels that can be used by subscribers to transmit signals to the network. The narrowband channels were originally intended for use in an educational setting (so-called wireless classrooms).

Because of recent deregulation that allows cable TV companies to provide telephone and Internet services, along with the development of digital technologies that make efficient use of available bandwidth, MMDS has considerable future potential. A MMDS network can provide high-speed Internet access, telephone/fax, and TV together, without the constraints of cable connections (www.wcai.com).

4.1.3 Satellite Data Networks

Satellite systems are established providers of fixed communication services including wireless WANs and VSAT (Very Small Aperture Terminal) networks. Of more interest to mobile users are some of the

ambitious large-scale networks comprised of LEO (Low Earth Orbit) or MEO (Medium Earth Orbit) satellite constellations and ground stations that are being launched aiming to provide broadband multimedia services. Some of the advanced satellite technologies that make this possible are switched spot beams, on-board processing and special orbits. Teledesic, Globalstar, Inmarsat, and Connexion by Boeing are subgroups of Satellite Data Networks, and are discussed below, including the services offered, terminals, coverage and costs. Propagation effects in mobile satellite systems are also included.

4.1.3.1 Teledesic

Teledesic is a global broadband data network (Internet-in-the-Sky) to provide worldwide, fiber-like access to telecommunications services such as computer networking, broadband Internet access, interactive multimedia, and high-quality voice, through Low Earth Orbiting (LEO) constellation of satellites. It is expected to cover nearly 100% of the Earth's population, and 95% of the landmass. This network whose objectives are to reach low latency, low error rates, high service availability, and flexible, broadband capacity, while serving as the access link between users or networks, is targeted to begin operating in 2005.

The Teledesic network consists of a space segment (the satellite-based switch network that provides the communication links among terminals) and a ground segment (terminals, network gateways and network operations and control systems). Terminals provide the interface both between the satellite network and the terrestrial end-users and networks. They perform the translation between the Teledesic Network's internal protocols and the standard protocols of the terrestrial world, thus isolating the satellite-based core network from complexity and change (Figure 1). Most users will have two-way connections that provide up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. The system enables the use of small, low-power user equipment to send and receive data. The fixed user equipment will mount on a rooftop and connect inside to a computer network or PC. Broadband terminals will offer 64 Mbps of two-way capacity. This represents access speeds up to 2,000 times faster than today's standard analog modems.

Teledesic's ability to handle multiple channel rates, protocols and service priorities provides the flexibility to support a wide range of applications including the Internet, corporate intranets, multimedia communication, and LAN interconnect. Teledesic's space-based network uses fast-packet switching. Communications are treated within the network as streams of short, fixed-length packets. Each packet contains a header that includes destination address and sequence information, an error-control section used to verify the integrity of the header, and a payload section that carries the digitally encoded user data (voice, video, data, etc.). Conversion to and from the packet format takes place in the terminals. From a network viewpoint, a large constellation of interlinked switch nodes offers a number of advantages in terms of service quality, reliability and capacity. The richly interconnected mesh network is a robust, fault-tolerant design that automatically adapts to topology changes and to congested or faulty nodes and links. To achieve high system capacity and channel density, each satellite is able to concentrate a large amount of capacity in its relatively small coverage area. Overlapping coverage areas plus the use of on-orbit spares permit the rapid repair of the network when a satellite failure results in a coverage gap. In the initial constellation, the Teledesic network will consist of 288 operational satellites, divided into 12 planes, each with 24 satellites.

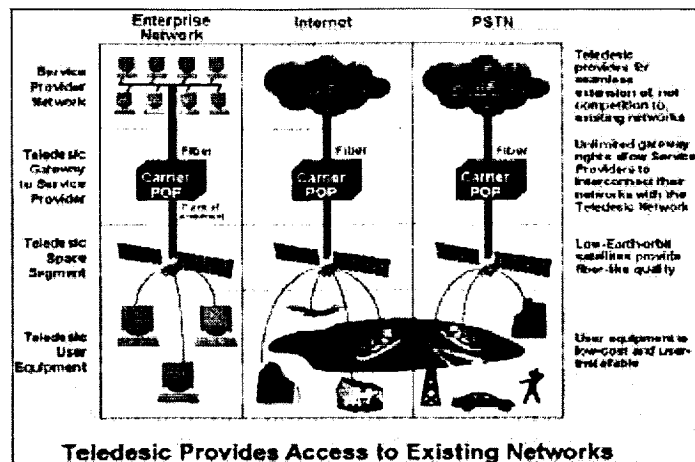


Figure 1. Teledestic network (www.teledestic.com).

The first investors of Teledestic are Craig McCaw, Bill Gates, Motorola, Prince Alwaleed Bin Talal Bin Abdul Aziz Al Saud, Abu Dhabi Investment Company, and The Boeing Company. The company was founded in 1990. Currently, initial system experiments are under way using a few LEO satellites. End-user rates will be set by service providers, but Teledestic expects rates to be comparable to those of future wireline options for broadband service.

4.1.3.2 Globalstar

Globalstar has a constellation of 48 Low Earth Orbiting (LEO) satellites that transmit calls from Globalstar wireless phones to a terrestrial gateway, where they are passed on to existing fixed and cellular telephone networks, facilitating global roaming. Globalstar uses a dual mode phone, which automatically switches to satellite mode, when out of cellular range, to provide continuous, seamless coverage to remote areas beyond cellular coverage. As in most satellite phones the antenna is larger and needs line of sight with the satellite, which means that it can be operated only outdoors. The system architecture consists of the following main components:

- Space segment consisting of the satellite constellation
- User segment consisting of the mobile, portable and fixed terminals
- Ground segment that consists of the gateway, the network controllers and the control and billing centers.
- Terrestrial network that links to the Public Land Mobile Network (PLMN) or the Public Switched Telephone Network (PSTN).

This system uses non-regenerative type satellite transponders that simply perform a transparent relay of the signals in the forward and reverse links. Globalstar uses narrow-band CDMA (Code Division Multiple Access) technology whereby the 1.23 MHz forward channel is divided into 128 narrow-band CDMA channels. The terminals have voice/ fax/ data, SMS and position location capabilities and are GSM compliant. It uses path diversity, which is a method of signal reception that combines multiple signals of varying power strengths into a single coherent signal. This needs simultaneous coverage of multiple satellites. Thus the satellite phones communicate with as many as three satellites simultaneously, combining those signals into a single, static-free signal. This leads to increased call reliability and voice clarity. Globalstar satellite phones also alter power levels to compensate for shadowing and interference as needed. As satellites move in and out of view, they are seamlessly added to and removed from the calls

in progress, reducing call interruption. The Globalstar protocol uses pilot assisted acquisition and power control (ref. 16).

4.1.3.3 Inmarsat

Inmarsat has been providing global voice and low rate data communications since 1982 and has continued to expand with additional satellite launches and evolved its aeronautical services with Aero-C, Aero-H, Aero-I, and Aero mini-M, which are designed to exploit the spotbeam power of the Inmarsat-3 satellites. The latest development in the Inmarsat network allows connection to a terrestrial ISDN network, leading to the 'mobile-IDSN' concept. ISDN (Integrated Services Data Network) is a communication network that uses digital technology to integrate voice, video and data on a single system.

Based on digital satellite technology via spotbeam, the Global Mobile ISDN Service offers not only a single service, but a complete system solution as well. The mobile satellite services are designed to connect fixed and mobile networks and close existing gaps in the telecommunications infrastructure. The capabilities are being designed to integrate corporate IT networks with global mobile satellite communications. It includes voice, fax and data transmission at speeds of up to 2.4 Kbps, as well as access to data transmission up to 64 Kbps (High Speed Data/HSD). In a second step, Inmarsat will launch the first and only mobile-satellite packet data service later in 2001 (Inmarsat Packet Data System, IPDS).

The Global Mobile ISDN introduces new applications for mobile users such as e-mail transfer, Internet and Intranet access, LAN applications, file and image transfer, video conferencing and remote working. It uses new portable units the size of a notebook computer and weighing around 4kg (9lbs). COMSAT is one of the companies that are developing networks and terminals for this service. It uses the Inmarsat satellite network and the Nera M4 satellite terminal to allow users to connect to low cost voice services as well as high-speed data services at data rates up to 64 kbps. By using standard ISDN interfaces, they will give access to a full range of desktop software via Inmarsat satellites.

4.1.3.4 Connexion by BoeingSM

Connexion by Boeing uses a satellite network to provide high-speed, two-way Internet and live television services, news and information to aircraft in flight, for about the same price as cellular phone services. Through this service, two-way, broadband (or high data-rate) connectivity will be delivered directly to the passengers with personalized and secure access to the Internet, company Intranets and live television and audio content. Connexion by Boeing will also provide airline personnel with information that will enhance operational efficiency on the ground and in the air (ref. 17).

The Connexion by Boeing service is currently available to the private business jet market. System installations on-board commercial airlines are expected to begin in 2001. Initial service will cover travel routes across North America and the service will be expanded to other global flight routes with an ongoing regional rollout through 2005. Specifically, Connexion by Boeing will serve three market segments below (as the service matures it will be extended to additional markets including commercial and leisure cruise ships and oil exploration platforms):

- Commercial airlines and their passengers
- Private business jets
- Government customers

Digital broadband capability, which provides increased bandwidth for two-way interactive applications, allows customers to send and receive data at rates equivalent to cable Internet access. To provide the capability to airborne travelers, Boeing will use advanced antenna technology and existing satellites, while extending to a mix of new and existing satellites as the service matures.

Customer airplanes will be equipped with the Boeing proprietary phased array receive and transmit antenna, a key enabler for two-way broadband communications. Initially developed by Boeing in 1986, the antenna technology provides a dramatic increase in data transmission capability over that currently existing today. The Boeing phased array antenna provides enhanced response to directional changes by steering signals electronically vs. mechanically, permitting instantaneous and continuous connections between satellites and customer aircraft.

4.1.3.5 Propagation Effects in Mobile Satellite Systems

There are special problems in the mobile-satellite services that are unique to them. For the land-mobile-satellite service, these problems involve effects of foliage, terrain, and man-made structures. For the aeronautical-mobile-satellite service, the issues involve long delayed echoes from the earth's surface. For aeronautical service, the altitude of the aircraft may be above most tropospheric attenuation and therefore airborne receivers will have an advantage over terrestrial receivers in receiving satellite signals. Ionospheric effects will be the same as for other service categories.

Satellite communications has the drawback that it requires direct line-of-sight (LOS) with the satellite and continuous tracking. While the tracking can be done with software and the antenna can remain fixed, the operation is limited to outdoor use. In addition, satellite signals can be weak and can thus require bigger antennas. However, these larger antennas can be detachable and improve the ease of installation.

4.1.4 Satellite Digital Audio Radio Services (S-DARS)

Direct broadcast satellite has been deployed in the last decade or so to deliver television broadcasting directly to homes from satellites via a VSAT (Very Small Aperture Terminal). This technology is now moving to the radio arena with direct broadcast of radio stations via satellite to mobile terminals in the vehicle. Thus a multitude of programmable digital channels will be broadcast directly from satellites to small, portable satellite receivers. Programming will be uplinked from ground stations to the satellites and then broadcast back to the subscribers on the ground (refs. 18, 19).

Programming choices range from news to entertainment to education. This is an interesting aspect of S-DARS - that due to the multitude of channels, dedicated channels may be allocated to various content providers, who are in charge of the programming for that channel. This means a sports channel with only sports and a weather channel with only weather available at all times. Another important feature is that the extensive coverage of the satellites in the geostationary orbit ensures a uniform, good broadcast quality with no fading over the entire continental United States and that these channels are always available at the same frequency everywhere with no need for tuning. The coverage aspect is the biggest advantage of S-DARS in terms of aeronautical application where en-route weather updates and warnings are required. Similar to the conventional radio, S-DARS is a one-way broadcast system.

The progress of this new technology began in 1992 when the FCC allocated spectrum in the "S" band (2.3 GHz) for nationwide broadcasting of satellite-based Digital Audio Radio Service (or "DARS") (ref.20). In 1997 the FCC had a spectrum auction and awarded licenses to two companies, CD Radio and XM Satellite Radio Inc. - formerly the American Mobile Radio Corporation.

4.1.4.1 Companies offering S-DARS

CD Satellite Radio, which is operating under the trademark Sirius Satellite Radio has launched three satellites and plans to deliver 50 channels of commercial-free music in virtually every genre, and up to 50 channels of news, sports, talk, comedy and children's programming. They will charge a monthly subscription fee of \$12.95 for this service. CD Radio's signal will be uplinked from a broadcast studio that will house the company's music libraries and facilities for programming and satellite uplinking.

The other operator, XM Satellite Radio has similar capabilities offering up to 71 music channels and 29 other channels featuring talk, news, sports and entertainment for a monthly subscription of \$9.99. Service is expected to be launched on September 10, 2001 in a few selected areas and November 12, 2001 nationwide. Both companies plan to employ terrestrial repeaters in major cities where buildings would block satellite reception.

A major thrust of both companies' business plans is to develop alliances with the major automobile manufacturers to build DBS-capable radios into new automobiles. XM Satellite Radio has an agreement in place with General Motors (GM), and Sirius Satellite Radio has agreements in place with Ford and Daimler-Chrysler. Both companies also have agreements in place with major radio manufacturers.

The equipment to receive the satellite signal will consist of an AM/FM/SAT receiver and a small, flat, 2" disk antenna will be attached to the windshield of the car. For use with existing equipment, a special adaptor card that is designed to slip into the cassette slot of the car stereo will be available. A small LCD panel will be available on new systems or attached to the card to display specific information about the broadcast. The technology to decode signals from a remote satellite, while the receiver is moving at a speed of 80 – 90 Mph, as well as deciphering the authorization information for the subscriber, is very advanced. Chip-sets for the new radio have to be capable of decoding of compressed data that will be used to squeeze up to 100 channels into a limited radio spectrum (ref. 21). The cost of equipment will be from \$200 to \$400 depending on the manufacturer.

Another company, Worldspace, currently delivers a satellite radio service to Africa, Asia, and the Middle East through the company's two L-band satellites, AfriStar and AsiaStar. The company plans on expanding their service to Latin America and the Caribbean sometime in 2001 with the launch of AmeriStar (ref. 22).

4.1.4.2 Future Planned Capabilities of S-DARS

The current systems do not have the capability for transmitting data and two-way request/reply services but due to the digital nature of the signals, receivers could be built to decode and display textual data in the future (refs. 23, 24). Both companies say that they are considering upgrading the system in the future to have possible integration of a Global Positioning System in the satellite radio receivers, and filtering the information content based on the position of the user to display location-sensitive information such as weather reports and traffic conditions. XM Radio and OnStar are also partnering together and in the next three years plan to develop a way to communicate between the two systems and use the higher capacity and speed of the satellite transmission to provide enhanced services to OnStar subscribers. The allocation of 2 – 3 channels to OnStar and the possibility of linking the user to the XM ground station via the OnStar centers will allow programmable content delivery and 2-way capability to be added to the system (ref. 24).

4.1.5 Third Generation Cellular Networks (3G)

Currently available solutions for data transfer over third generation cellular networks include the Short Message Service (SMS), which allows a basic e-mail exchange, and the traditional low speed Circuit Switched Data (CSD), which may be used to access Internet services. The main drawbacks of CSD are the very limited bandwidth capacity (9.6 kbps or 14.4 kbps depending on the employed coding scheme) and the sub-optimal use of the radio interface. A straightforward extension of CSD is the High Speed Circuit Switched Data (HSCSD), which increases the transmission capacity by allocating to a single user up to 8 CSD channels. However this solution still makes use of the radio resources in circuit switched mode, and is therefore poorly optimized for the bursty traffic profile generated by most of Internet applications.

Aiming to provide more bandwidth as well as more efficient spectrum usage, most of GSM (Global System for Mobile Communications) operators are currently deploying the General Packet Radio Service (GPRS), which is a fully packet oriented technology designed to support both IP and X.25 and supports data transmission rates up to 115 kb/s. GPRS provides a data overlay within the standard GSM infrastructure (with some new functional elements). The evolution of data communication in cellular networks is illustrated in Figure 2.

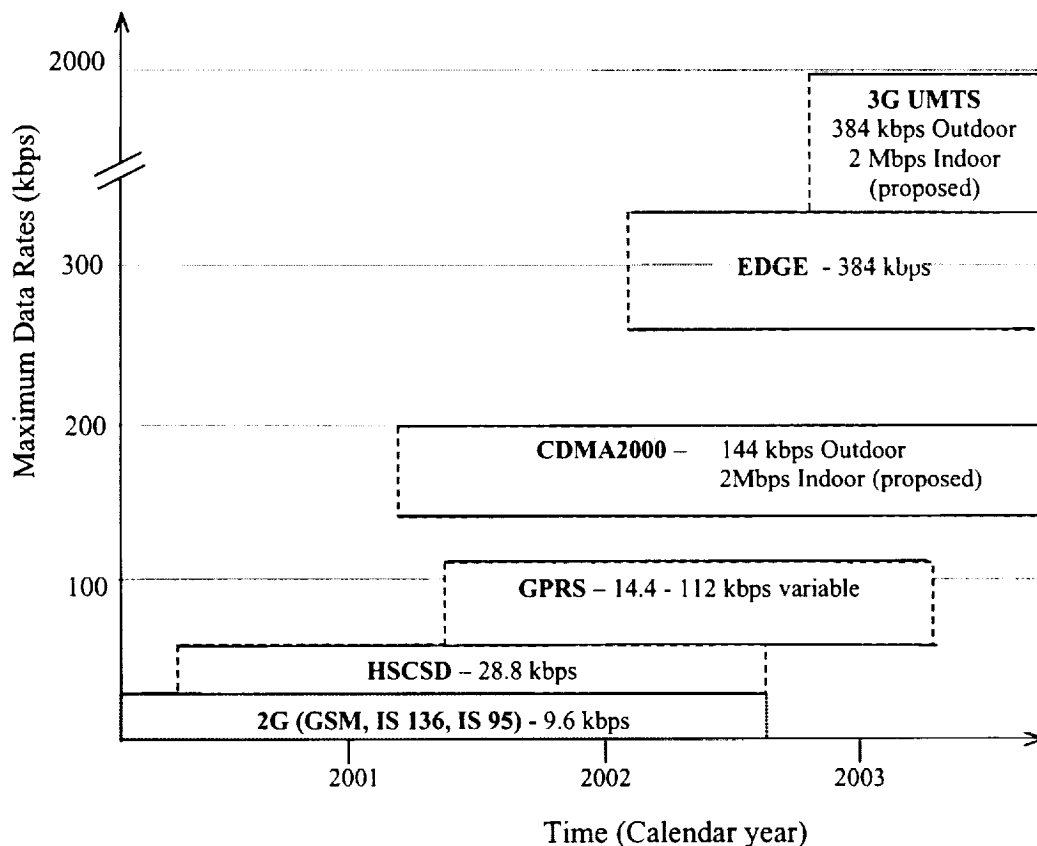


Figure 2. Evolution of data over cellular networks.

The vision of true broadband mobile systems, with sophisticated networks, which provide seamless connectivity and support of various classes of users with their personal profiles and mobility levels, is known as UMTS (Universal Mobile Telecommunications System) in Europe or IMT 2000 in its ITU version. This is a result of collaboration of many entities inside the ITU (ITU-R Radiocommunication Sector and ITU-T Telecommunication Standardization Sector) and outside the ITU such as the European 3GPP (Third Generation Partnership Project). UMTS also has the support of many major telecommunications operators and manufacturers because it represents a unique opportunity to create a mass market for highly personalized and potentially revenue generating applications for the growing number of mobile users.

UMTS seeks to build on and extend the capability of today's mobile, cordless and satellite technologies by providing increased capacity, data capability and a far greater range of services using an innovative radio access scheme and an enhanced, evolving core network. UMTS aims to speed convergence between telecommunications, IT, media and content industries to deliver new services and create fresh revenue-generating opportunities. It will also enable connection and access to high-speed broadband fixed networks such as ISDN, frame relay and asynchronous transfer mode (ATM). 3G systems require additional radio frequencies to cater to growth in demand and to make use of technology that has been specifically designed for bandwidths higher than those used in today's 2G networks. Revenues from 3G will come from two main sources: charging for network access and airtime, and charging for content and value-added services or transactions.

In Europe, the groundwork for UMTS started in 1990. R&D programs sponsored by the European Union such as RACE (Research into Advanced Communications for Europe) (1990-1994) and ACTS (Advanced Communications Technologies and Services) (1994-1998) played a major role in developing and testing the technology, including satellite UMTS access. ACTS work culminated at the January 1998 meeting of ETSI (European Telecommunications Standards Institute) that endorsed UMTS terrestrial standards developed under the ACTS framework. The UMTS/IMT-2000 services are categorized in Table 6 (ref. 25).

Table 6. Service classes and attributes.

Services	User net bit rate [kbps] (maximum)	Coding factor	Asymmetry factors	Call duration (effective) [s]	Service bandwidth ¹ [kbps]	UMTS Switch Mode ²
Low interactive Multimedia (MM)	128	2	1/1	180 (144)	256/256	CS
Medium speed MM	384	2	0.026/1	14	20/768	PS
High Speed MM	2000	2	0.005/1	53	20/4000	PS
Switched data	14	3	1/1	156	43/43	CS
Simple messaging	14	2	1/1	30	28/28	PS
Speech	16	1.75	1/1	120 (60)	28/28	CS

¹ The service bandwidth is the product of columns 2, 3 and 4

² CS is circuit switched and PS is packet switched

4.1.5.1 S-UMTS

S-UMTS is the Satellite component of the UMTS. It is expected to handle various forms of information such as speech (voice), image and data, and will provide an extension to the terrestrial 3G wireless networks. Due to the differences between terrestrial and satellite channel characteristics, some modifications to the terrestrial UMTS standards are necessary. Some specifications are directly applicable, whereas others are applicable with modifications.

The ETSI S-UMTS Technical Specifications are comprised of several parts:

- Part 1: Physical channels and mapping of transport channels into physical channels (S-UMTS-A 25.211)
- Part 2: Multiplexing and channel coding (S-UMTS-A 25.212)
- Part 3: Spreading and modulation (S-UMTS-A 25.213)
- Part 4: Physical layer procedures (S-UMTS-A 25.214)

MSS (Mobile Satellite Services), which is one of the application areas of S-UMTS, have been categorized as follows:

1. Speech - quality basic speech at 8/16 kbit/s
2. Low-speed data - predominantly messaging and e-mail (without attachments) type services at 9.6/16 kbit/s
3. Asymmetric services - this includes the predominantly one way services including file transfer, database/LAN access, Intranet/Internet WWW, E-mail (with attachments), image transfer etc. Rates of transmission will be up to around 144 kbit/s. This corresponds approximately to the Medium (and High) Multimedia services defined for terrestrial UMTS/IMT-2000
4. Interactive Multimedia - predominantly relating to videoconferencing and videotelephony at data speeds of around 144 kbit/s. This corresponds approximately to the High Multimedia services as defined for terrestrial UMTS/IMT-2000.

The UMTS is aiming to provide a network capable of supporting many data rates and over-the-air change in data rates, in response to the type of service requested by the user as well as network conditions such as usage. Thus, a user making a file download can request a higher data rate for the period of time that the network can allow and then switch to a lower data rate when more users connect to the network. These VDR (Variable Data Rate) services are made possible by enhanced radio architectures and receiver technologies such as software radios.

In Europe, the definition work for a possible S-UMTS system has been extensively carried out by the European Union's ACTS (Advanced Communications Technologies and Services) program. The ACTS program is framework for EU's research effort to accelerate deployment of advanced communications infrastructures and services and consists of over two hundred individual projects and trials including MOMUSYS (Mobile Multimedia Systems), TOMAS (Inter-Trial Testbed of Mobile Applications for Satellite Communications) and SINUS (Satellite Integration into Networks for UMTS Services) projects (ref. 26).

Preliminary results achieved by project SINUS are pushing the state of the art in topics like UMTS intra-satellite segment handover, inter-segment handover and reference models for satellite integration with the terrestrial systems. The project is undertaking full characterization of system performance for a

variety of mobile environments (suburban, rural, etc.) and support of multimedia applications. Through trials, the Ka band satellite concepts recently proposed for FSS (Fixed Satellite Service) applications (by Teledesic, Spaceway, Cyberstar etc.) have been successfully extended to mobile applications.

Joint trials by a number of ACTS projects have been set up to validate innovations in S-UMTS equipment and services on real mobile satellite channels. The foremost technology being investigated for S-UMTS is the satellite W-CDMA (Wideband Code Division Multiple Access) - the European Space Agency (ESA) is working on Radio Transmission Technology (RTT) which is the adaptation of UMTS W-CDMA to the satellite environment. Code Division Multiple Access (CDMA) scheme is being tested by SINUS because it offers several benefits over other schemes and maximum compatibility with the terrestrial W-CDMA mode. The proposed trials aim at covering a whole range of orbits, from LEO (780 km) up to GEO, with use of variable parameters (e.g. for power control or interleaving depth). Beyond the need to harmonize the satellite access with terrestrial solutions, work under both ESA and SINUS project have concentrated on CDMA for the following reasons:

- Satellite diversity is an essential feature considering the required service availability rates and it is easy to combine signals from a number of sources such as multiple satellites with CDMA.
- Easier to access to different types of constellations such as LEO or GEO as it is easy to resolve time delay in CDMA.
- CDMA allows soft handover, which is a seamless handover, achieved with user's terminal communicating with both base stations simultaneously.
- Simpler radio resource management, TDMA requires a more complex frequency planning between the satellite spots.
- CDMA offers high capacity solutions.

Although extensive W-CDMA technology trials are currently being run by a large number of operators for terrestrial UMTS, presently the satellite W-CDMA remains largely untested.

4.2 Device Technologies for Wireless Connectivity

While the data networks described in the previous section provide the infrastructure for the communication system, the wireless devices provide the link between the service provider and the end user's final requirements. "Faster, smaller, better" are the guidelines that have driven the design of wireless devices. Selected device technologies such as operating systems, air interface / wireless modem, and Bluetooth are discussed in this section.

4.2.1 Operating Systems

There are operating systems specifically developed for handheld and in-vehicle devices that provide an open architecture for the development of independent and add-on applications. Examples of such operating systems are the Windows CE by Microsoft, Palm OS by Palm Inc., and Symbian's Epoc. The development platform for real-time tools and applications for mobile devices uses a number of powerful languages such as Java and Wireless Access Protocol (WAP). Java provides superior usability needed for functions such as maps, other navigation applications, and operating system independence. Applications written in Java can run on a variety of devices such as set-top boxes, smart phones, vending machines, and handheld order-entry or inventory devices. An example of application software that can be created using Java is a keypad on a handheld device, such as a Palm Pilot screen.

4.2.2 Air Interface / Wireless Modem

Air interfaces are the protocols that define the physical layer characteristics of the communication scheme, and allow the signal to be extracted. The most common air interface is the wireless modem, which is essentially a wireless transceiver that consists of all the RF, modulation/demodulation, analog to digital and digital to analog conversion circuitry necessary to transmit over the channel. Modems are designed according to the particular communication scheme used.

One of the most critical components of the wireless modem that affect the transceiver performance is the RF power amplifier. This component introduces nonlinearities and intermodulation noise, if not designed properly. Hence it is one of the most expensive components in a wireless modem. A variety of commercial off-the-shelf modems are available for the different communication standards. Another benefit of modem standardization is that since the same components are used for a variety of different manufacturers' devices, the volume is increased, achieving economy of scale.

4.2.3 Bluetooth

The Bluetooth wireless technology allows users to make wireless and instant connections between various communication devices, such as mobile phones and desktop and notebook computers. Since it uses radio transmission, transfer of both voice and data is in real-time. It supports both point-to-point and point-to-multipoint connections. It is an RF (radio frequency) -based technology geared toward cable or IR replacement that allows interoperability between different devices.

The Bluetooth radio is built into a small microchip and operates in a globally available frequency band ensuring communication compatibility worldwide. The Bluetooth specification has two power levels defined: a lower power level that covers the shorter personal area within a room, and a higher power level that covers a medium range, such as within a home.

3Com already has products that include Bluetooth technology (PC Card, USB Adapter, and Access Point 1000), which will be available in the first half of 2001. This technology will be used on a broad range of computers, cell phones, Palm computers, printers, scanners, keyboards, digital cameras, and other devices. All personal digital devices will be connected in the user's personal area network (PAN). For example, a user's handheld device and desktop system will automatically synchronize her/his schedule and address books while his/her cell phone updates its phone number list.

The historical development of Bluetooth begins with Ericsson Mobile Telecommunications' initiation of a study to investigate the feasibility of a low-power, low-cost radio interface between mobile phones and their accessories in 1994. The objective on this was to eliminate cables between mobile phones and PC cards, headsets and desktop devices, etc. In February 1998, 5 companies formed a Special Interest Group (SIG), including Nokia, IBM, Toshiba, and Intel. The mission of the SIG was to define and promote an open, royalty-free specification for seamless, wireless connectivity and cable replacement for a wide variety of mobility-enhancing devices. Today, the SIG includes promoter companies such as 3Com, Ericsson, IBM, Intel, Lucent, Microsoft, Motorola, Nokia and Toshiba, and more than 2000 Adopter/Associate member companies.

4.3 Challenges to Deployment of Wireless Technologies and Some Solutions

Key information on wireless technologies was provided in the previous sections of chapter 4. Vehicular communication systems work in a fast moving mobile environment that introduces a host of complexities not encountered in a fixed or indoor portable environment. An overview of some of the technical as well as organizational challenges is considered in this section. Additionally, some of the techniques to address the key challenges are presented in a table.

The challenges include the effects of fading and Doppler effects. Broadband systems are more susceptible to fading since fading is frequency selective and therefore more likely to affect part of the wide frequency band. Doppler shift arises from the relative motion of the transmitter and receiver, causing a frequency shift. This frequency shift varies according to velocity, direction, and the type and number of scatterers involved in the path, and introduces random frequency modulation on the signal. The radio channel suffers from periodic fades as the mobile receiver moves in the radio environment. When the signal is in fade (i.e. it drops below the signal threshold), bursts of errors are likely to occur and the time that it falls below this limit provides an estimate of the size of the error burst. The average fade duration of a signal depends on the propagation frequency and speed of the mobile unit. Hence a slow moving portable terminal suffers considerably larger error bursts due to the longer time spent in a fade than a fast-moving mobile terminal. Therefore, the portable is more likely to suffer larger error bursts. Very often, due to low signal-to-noise levels, additional mechanisms contribute to the causes of burst errors, such as loss of synchronization. For example, the GSM system in Europe has a bit period of 3.69 μ s (for a data rate of 270 kbps). In order for the GSM system to operate successfully without interference caused by signal overlap from delayed/echoed pulses, some form of adaptive equalization is required. The data structure in GSM incorporates an equalizer sequence, which equips the mobile device to tolerate delay spread, making them capable of operating in most environments.

Short intermittent burst errors in short data packets can be corrected by Automatic Repeat Request (ARQ), while longer burst errors caused by deep fades can be overcome by a combination of forward error correcting codes and interleaving with interleaving length equal to the packet size. Some of the common technical challenges and their corresponding solutions are highlighted in Table 7, the key technical challenges being:

- developing tracking, high-gain vehicular antennas,
- designing power efficient communications schemes,
- compensating for high rain attenuation, and
- overcoming high Doppler shifts and frequency uncertainties.

Table 7. Common Technical Problems in Mobile Communication Systems

Problems	Causes	Solutions
Frequency offsets	Doppler shift, oscillator instabilities	Pilot tracking, Doppler pre-compensation, use of DDS techniques for digital oscillators.
Phase noise i.e. random phase fluctuations.	Oscillator jitter esp. in high switching frequencies. Appears as sideband noise on both sides of the carrier.	Robust modulation that overcome degradation due to phase noise and coherent de-modulation.
Rain attenuation esp. in satellite links.	Rain causes fading of the electromagnetic waves.	Rain compensation algorithms (RCA) using pilot power measurements.
Problems	Causes	Solutions
Fading	Atmospheric attenuation to the propagation of radio waves.	UPC (Uplink power control)
Deep short-term shadowing	Blockage due to tall buildings, mountains etc.	Modem built to compensate for this by 'free wheeling' and not losing synchronization. SAW filter

5 Market Analysis and Technological Implications for General Aviation

In-Vehicle Information Systems in the automotive and trucking industry and selected enabling communication technologies were discussed in the previous sections, in order to build an information basis. This section provides a General Aviation (GA) market analysis to develop an understanding of the GA market and its parallels with the A/T industry in terms of on-board information systems. With this goal, GA market needs were investigated by means of a survey conducted at the AirVenture 2000 Experimental Aircraft Association (EAA) Convention in Oshkosh, Wisconsin. Results of this survey are analyzed in this chapter, in order to determine initial market analysis of weather information systems in General Aviation (GA).

The history of GPS market acceptance provides an example of market trends for products similar to cockpit weather systems. As a result, this section also analyzes findings on GPS market acceptance history to characterize the GA market technology penetration patterns. Using weather information products recently introduced to the aviation market and discussions with the A/T industry and the GA market research, possible technological implications of the on-board information systems used in automobile and trucking industry for GA cockpit systems are discussed. This analysis begins with the Oshkosh survey.

5.1 Oshkosh Survey Analysis

Information from the Oshkosh survey and data describing GPS market acceptance in the aviation and car navigation segments can be used to characterize new technology penetration patterns in the GA market. This section focuses on the survey that was conducted at the AirVenture 2000 Experimental Aircraft Association (EAA) Convention in Oshkosh, Wisconsin, from July 26 to August 1, 2000. The EAA is an organization whose members have a wide range of aviation interests and backgrounds. Among its members, there are a large number of pilots (from recreational to commercial), who fly a wide range of different aircraft. Survey questionnaires were taken to the convention and presented to pilots only, to be filled out. There were 139 total participants, with 6 recreational, 58 private, 14 instrument rated, 28 commercial, and 12 air transport pilots. The remaining 21 did not specify a particular pilot category.

The survey questions were selected based on current research on existing weather information systems in the GA market and addressed possible information system developments identified during additional research on parallel technologies used in the automotive and trucking industry.

The survey consisted of five main sections with several sub elements in each. These sections requested data about existing weather information systems that participants currently have, difficulties in using current systems, desired weather information update frequencies, features participants would like to have in the future, and costs that they are willing to pay to have these future systems. Most of the options require the use of a 1 – 5 scale to determine the level of preference or importance, 1 being least preferred or important, 5 being most preferred or important. The results of the main sections of the survey are summarized in the following subsections. The second page is for the analysis part of this study (Weather Information Systems for GA Pilots), while the first page is related to another project about TAMDAR (Tropospheric Airborne Meteorological Data Reports).

5.1.1 Current Weather Related Equipment

This section of the survey asked pilots the questions below, regarding current equipment in use, and common problems with these systems. Responses follow each question.

Question: Describe your current communication method to obtain weather information during flight.

- Radio
- Airborne cellular
- Ground based VHF
- Satellite LEO / MEO
- Satellite Geo-synchronous

Results of the answers to this question are shown in Figure 3 and indicate that nearly 80% of the respondents use radio as the current communications method.

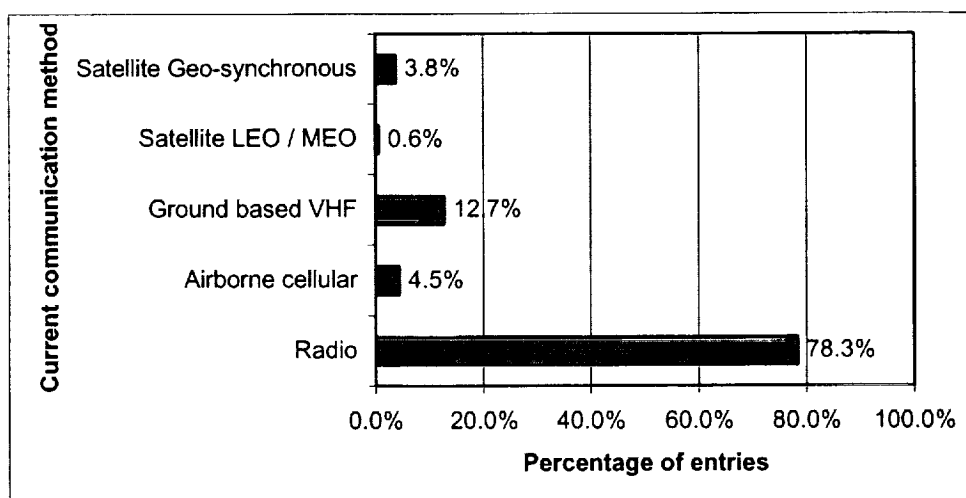


Figure 3: Current Communication Method

Question: What are the difficulties in using your weather - related equipment (please note all that apply)? How critical are they? (Please use 1 to 5 scale, 5 being most critical, 1 being least critical).

- Dead (communication loss) in some areas
- Channel busy
- Lack of clarity
- Incorrect weather information

Figure 4 shows the answers to this question and indicates that, although all factors were problematic, lack of clarity and communication loss are the two most important factors in using weather related equipment.

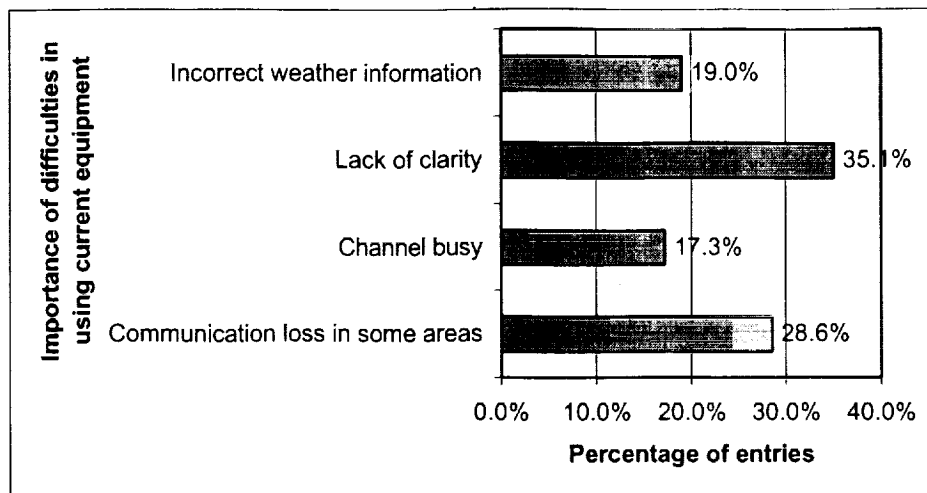


Figure 4. Current difficulties in using current equipment.

Question: How often do you currently get in - flight weather updates and how often would you like them in the future?

- 0 – 5
- 5 – 9
- 10 – 14
- 15 – 20
- 20 – 25
- Other
- *What is the desired future update interval?*

Results of the answers to this question are shown in Figure 5. This indicates that 84.3% of the pilots get weather updates less frequent than every 5 minutes. On the other hand, based on the answers to the desired future update interval, 93% of the pilots would like to have weather updates more frequent than every 5 minutes.

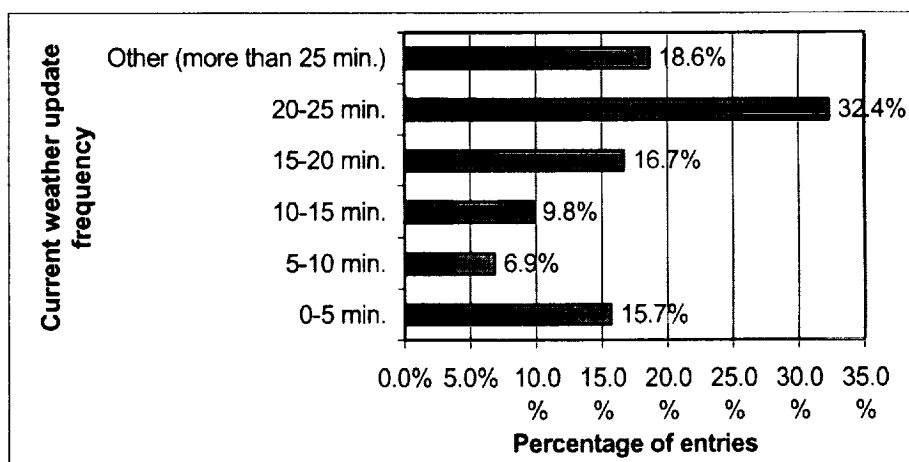


Figure 5. Current weather update frequency.

Table 8 summarizes the analysis of weather information system related questions.

Table 8. Analysis of current weather information systems.

	Current information	Percentage of entries
Current communication method (Total entries: 157)	Radio	78.3%
	Other (Airborne Cellular, ground based VHF, satellite LEO/MEO, satellite geo-synchronous)	21.6%
Most important difficulties in using current system (Total entries: 168)	Communication loss	28.6%
	Busy channel	17.3%
	Lack of clarity	35.1%
	Incorrect weather information	19%
Current weather update frequency (Total entries: 102)	Less than 15 minutes	32.3%
	More than 15 minutes up to 4 hours	67.7%
Desired weather update frequency	Less than 5 minutes	93%

5.1.2 Display Hardware

The second part of the survey asked participants to describe the weather information display hardware they desire in the future. The options were:

- Integrated into the current cockpit display system
- Separate, stand-alone, dedicated weather display
- Tethered – hard wired into cockpit systems, but moveable location
- Portable display that is useable in cockpit and / or on the ground, such as:
 - Integrated to your lap top
 - Integrated to your palm pilot
 - Separate dedicated weather display

Figure 6 shows that the most popular participant selections involved integration of the display into the cockpit and the portable option. Figure 7 breaks out the preference of those who selected the portable display option. Therefore, the percentages in Figure 7 are out of the 35% participants who selected portable option in Figure 6. Figure 6 shows that 48.4% of the participants would like to have a display hardware integrated into the cockpit's front panel. Additionally, 35% of them prefer portable display hardware. Figure 7 indicates that out of this 35% participants who selected portable option in Figure 6, 75.6% prefers integration to a personal laptop or palm pilot. Therefore, integration (whether to the cockpit's front panel, or to a personal electronic device) is an important aspect for the display hardware of a future weather information system.

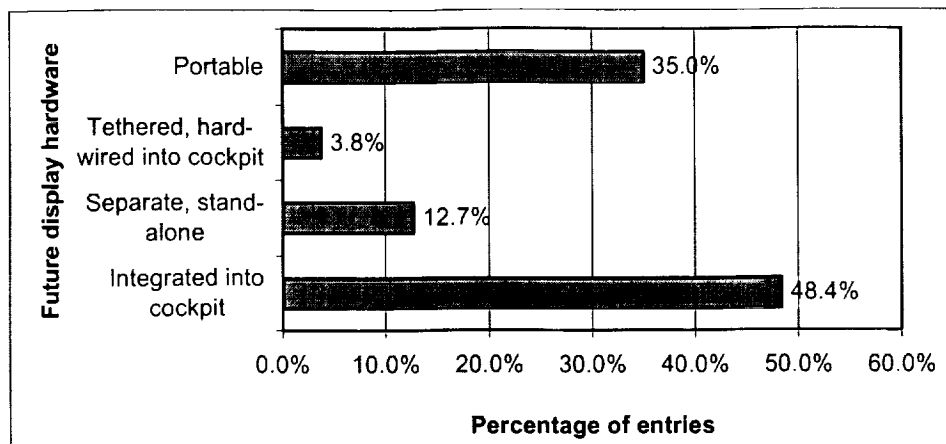


Figure 6. Preference of future display hardware.

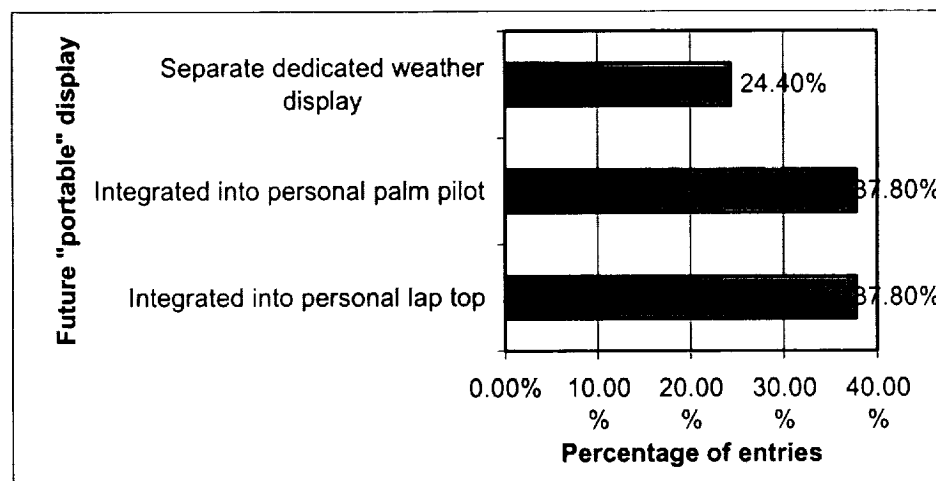


Figure 7. Preference of future display in case it is portable.

5.1.3 Preferred Features in the Future Equipment

The question asked in this part of the survey was as follows: *What features would you like to have on your future system (please note all that apply)? How critical are they? (Please use 1 to 5 scale, 5 being most preferred, 1 being least preferred).*

This section consists of six subsections below:

- *Messaging*, including three options: text messages, graphical data, and two-way communication with the ground service provider.
- *Geographical data*, including three options: text GPS, moving map GPS, and 3-dimensional terrain visualization.
- *Display*, including four options: monochrome, color display, LCD, and CRT.
- *Pilot data entry to the system*, including five options: touch-screen (with no classification on bezel buttons), voice recognition, keyboard, mouse, and menu driven with limited keypad.

- *Combined weather-related information*, including three options: weather alert system about the conditions ahead, trend data from past weather conditions, and weather situation reporting to the ground.
- *Non-weather services*, including four options: aircraft performance report to the pilot, aircraft location information to the ground, personal messaging, and Internet access.

Figure 8 summarizes the results of this section. Graphical messaging is the most desirable choice as a messaging feature, with 81.3%. 92% of the participants prefer three-dimensional terrain visualization as geographical data. LCD (86%) and color (82.6%) displays are leading display options. The pilots would also like to have touch-screen data entry into the system (74%). Weather alert system about the conditions ahead (88.3%) is in the lead among combined weather-related information options. Non-weather service options are close: Aircraft performance report to the pilot with 39%, aircraft location information to the ground with 36%, and Internet access in cockpit with 27%.

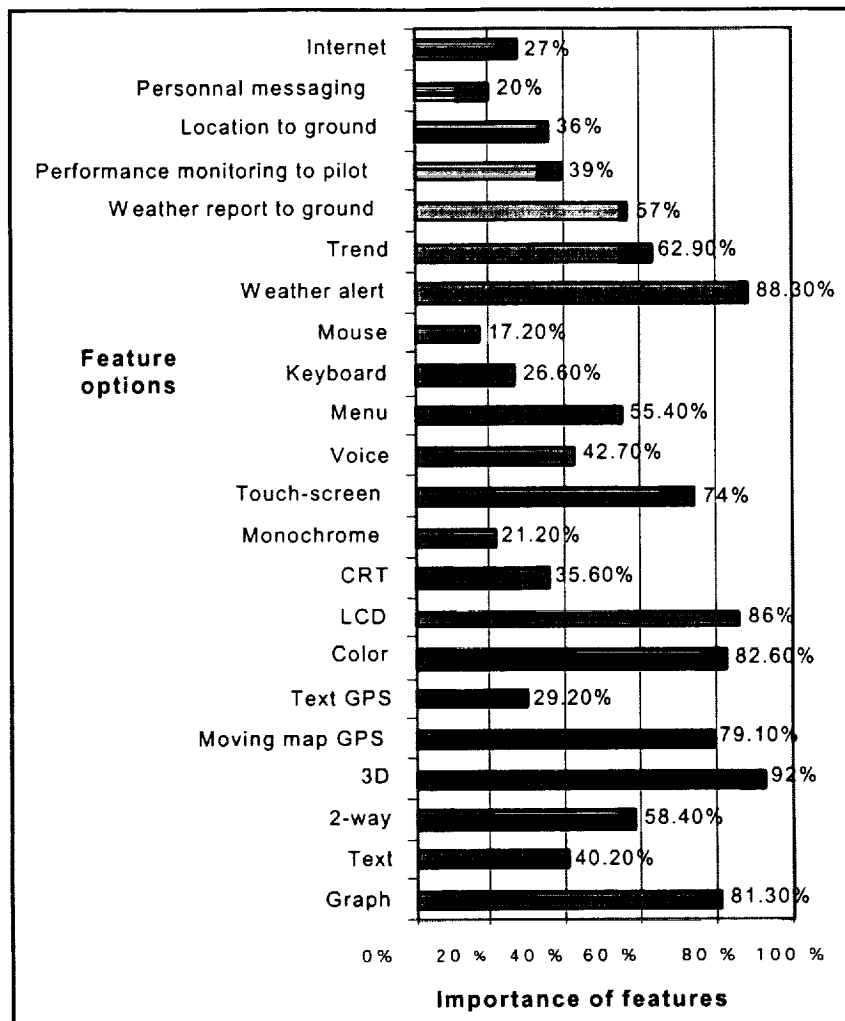


Figure 8. Importance of possible features of the future equipment.

5.1.4 Non-Recurring Costs

Non-recurring costs are one-time costs such as product price and installation costs. Pilots were asked how much they (or, their company) would be willing to pay to purchase and install the equipment that they rated as 4 or 5 in the previous sections, if it were available today. The options varied as:

- \$ 0 – 250
- \$ 251 – 500
- \$ 501 – 700
- \$ 701 – 1,000
- \$ 1,001 – 1,500
- \$ 1,501 – 2,000
- \$ 2,001 – 3,000
- \$ 3,001 – 5,000
- \$ 5,001 – 10,000 or,
- Specify \$.

Figure 9 shows the accumulation of the pilots that are willing to pay these non-recurring costs, based on the survey results. The actual numbers are stated in table 9.

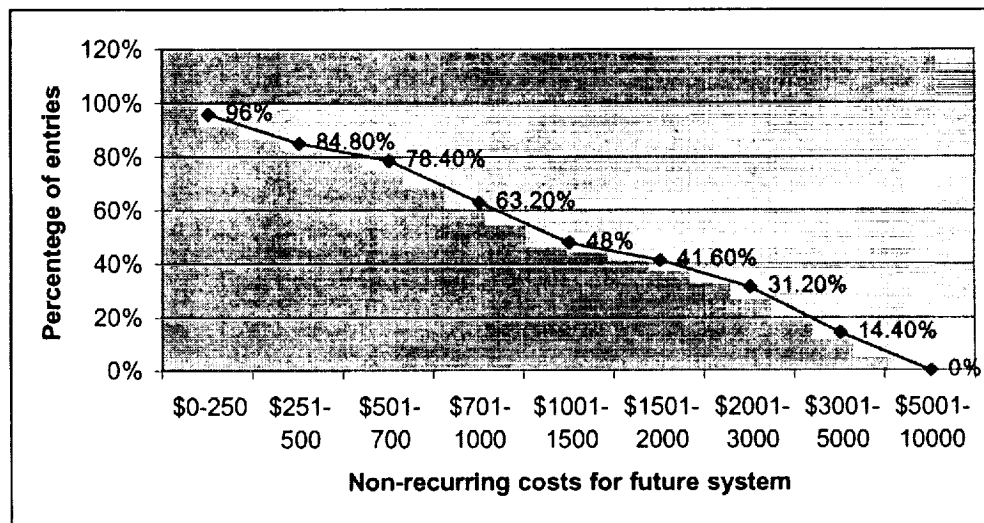


Figure 9. Non-recurring costs for the future system (accumulated).

Table 9. Actual numbers for non-recurring costs vs. percentage of pilots.

Non-recurring costs	Percentage of pilots
\$0 – 250	4%
\$251 – 500	11.2%
\$5,01 – 700	6.4%
\$701 – 1,000	15.2%
\$1,001 – 1,500	15.2%
\$1,501 – 2,000	6.4%
\$2,001 – 3,000	10.4%
\$3,001 – 5,000	16.8%
\$5,001 – 10,000	14.4%

Based on the results indicated in Figure 9, non-recurring costs for the future system can be grouped in two categories in Table 10. According to this, the participants can be divided into two large groups. 41.6% of them will pay less than \$2,000 for non-recurring costs, while 58.4% of them will pay more than \$2,000. This is an interesting result, and will be further discussed in Section 5.1.6.

Table 10. Analysis of non-recurring costs.

Non-recurring costs	Percentage of entries
Less than \$2,000	41.6%
More than \$2,000 up to \$10,000	58.4%

5.1.5 Recurring Costs

Recurring costs are continuous costs such as per-service, monthly, or annual service costs. These can be referred as "fees." Pilots are asked how much they (or, their company) would be willing to pay for the annual fees of the continuous information services from the ground service provider, if they were available today. The options were:

- \$ 0 – 300
- \$ 301 – 500
- \$ 501 – 700
- \$ 701 – 900
- \$ 901 – 1,100
- \$ 1,101 – 1,200
- \$ 1,201 – 1,500
- \$ 1,501 – 2,000
- \$ 2,001 – 2,500 or,
- Specify \$.

Figure 10 shows the accumulation of the pilots that are willing to pay these recurring costs, based on the survey results. The actual numbers are stated in table 11.

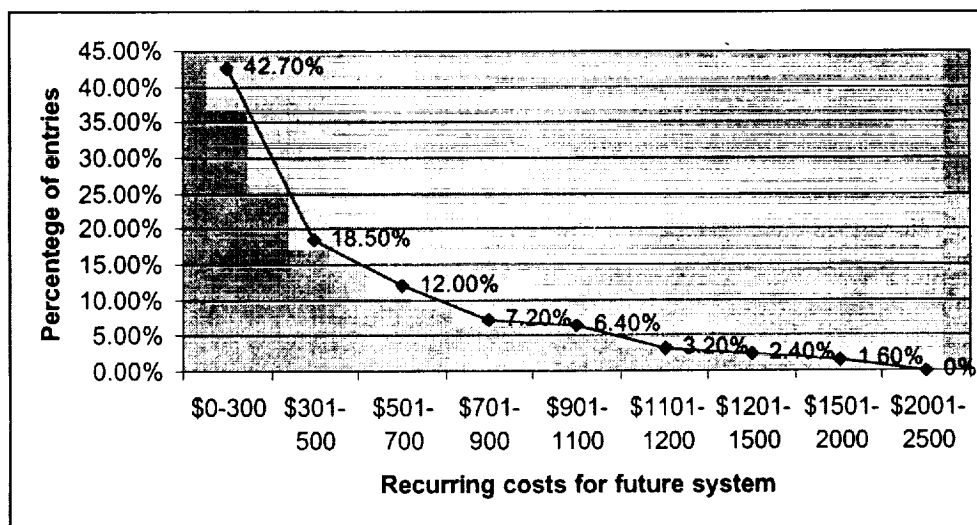


Figure 10. Recurring costs for the future system (accumulated).

Table 11. Actual numbers for recurring costs vs. percentage of pilots.

Recurring costs	Percentage of pilots
\$0 – 300	57.3%
\$301 – 500	24.2%
\$5,01 – 700	6.5%
\$701 – 900	4.8%
\$901 – 1,100	0.8%
\$1,101 – 1,200	3.2%
\$1,201 – 1,500	0.8%
\$1,501 – 2,000	0.8%
\$2,001 – 2,500	1.6%

Based on the results indicated in Figure 10, recurring costs for the future system can be grouped in two categories in Table 12. Most of the pilots would not like to pay more than \$500 for recurring costs. Therefore, even if the non-recurring costs are relatively high, recurring costs should be kept low for the future systems.

Table 12. Analysis of recurring costs.

Recurring costs	Percentage of entries
Less than \$500	81.5%
More than \$500 up to \$2,500	18.5%

5.1.6 Survey Analysis

This section summarizes and integrates the results of the survey. According to the survey responses, 78.4% of the participant pilots use weather radio to receive weather information. The most important difficulties they face in using this current equipment are lack of clarity and communication loss in some areas during flight. They currently receive weather updates less frequently than every 15 minutes, which is not adequate since they would like to be informed about the weather conditions more frequently than every 5 minutes. In summary, current weather information equipment, which is used by majority of the 139 participants, needs to be improved, or replaced by another system.

Survey participants identified desired characteristics of the future system. They would like to have a system with display hardware integrated into the cockpit's front panel (48.4%), or portable (35%). If the system is portable, they prefer it to be integrated into their personal palm pilot or laptop. This means that the integration of the future system into other information technologies is desired. In fact, this is usually the case when information systems such as GPS are considered (ref. 27). Participants indicated that the following features are most desirable, in their future system:

- Graphical messaging (81.3%)
- Three-dimensional terrain visualization (92%)
- LCD (86%) or color (82.6%) display
- Touch-screen data entry into the system (74%)
- Weather alert system about the conditions ahead (88.3%)
- Non-weather services are close to each other: Aircraft performance report to the pilot with 39%, aircraft location information to the ground with 36%, and Internet access in cockpit with 27%.

Most participants are not willing to pay more than \$500 as recurring costs, which are annual fees for continuing services. So that, independent from the non-recurring costs, which are the costs for purchasing and installing the equipment, recurring costs should be in this range to satisfy these customers.

Participants are divided almost evenly in terms of non-recurring costs as indicated in table 9. 58.4% of them are willing to pay more than \$2,000 up to \$10,000, while 41.6% would like to have a product for less than \$2,000. To further analyze this result, the participant responses were broken down into professional categories since professional affiliation might be an important parameter that affects preference of non-recurring costs. In Table 11, a breakdown of non-recurring costs is shown with respect to pilots' professions. It indicates that most of the private, instrument rated and commercial pilots are not willing to pay more than \$2,000 for purchasing and installing the future system. Among these, commercial pilots are the ones who make a relatively larger contribution to the higher price range. This is reasonable since private and instrument rated pilots are usually not profit based, but personal interest oriented, while commercial pilots are more for-profit based. Recreational pilot data does not add value to the analysis since they divide evenly between the two price ranges. Air transport pilots who are usually airline pilots are willing to pay more than \$2,000. This is probably due to their high disposable income level, or their companies' affordability.

Table 11. Non-recurring costs that pilots are willing to pay (Breakdown with respect to profession).

Pilot Professions	Less than \$2,000	More than \$2,000 up to \$10,000
Private Pilots	72%	28%
Instrument Rated Pilots	71%	29%
Commercial Pilots	61%	39%
Air Transport Pilots	33%	67%
Recreational Pilots	50%	50%

5.2 GPS Market Acceptance

In characterizing the steps of GA market acceptance in this research, GPS was considered a good candidate to study as an example of information technology penetration. Based on this information, it is possible to estimate the market growth patterns for future information system products, such as weather information systems.

While considering technology transfer from the automotive and trucking industry to GA in terms of on-board weather information systems, basic similarities between these technologies and GPS are realized. For example, GPS is another information technology that is used both in automotive and trucking and aviation industries. It is an example of the same technology application to both public needs and commercial enterprise. Especially in the aviation market, improving safety is one of the main purposes of using GPS, even more important than price (ref. 28).

This section covers the market acceptance history of GPS from its first introduction to civil use (1993) to year 2000. The data presented in the following chapters are taken from a U.S. Department of Commerce Report submitted on September 1998 (ref. 28). This report includes detailed information on worldwide GPS sales and market projections for market segments such as car navigation, aviation, marine, military, consumer, tracking/machine control, OEM, and survey/mapping/GIS. In this study, only GPS worldwide sales data in car navigation and aviation segments are considered, in order to identify possible similarities between them, and to have a closer look at the aviation market.

5.2.1 Historical Development of GPS

There are many milestones in the history of GPS development. Since the NAVSTAR GPS concept was approved in 1973, essentially every year has consistently shown a significant development step. 1993 was especially significant since the U.S. declared Initial Operational Capability of GPS, with 24 satellites in orbit. This decision accelerated the worldwide commercialization of the product and, consequently, revenue values are considered beginning from 1993 to 2003 in this study. Some of the important milestones in GPS development are stated below (ref. 27).

1973: NAVSTAR GPS concept is approved.

1974: First satellite is launched.

1983: President Reagan offers to make GPS available for civilian aircraft when the system becomes operational.

1990: Trimble Navigation, the world leader in commercial sales of GPS receivers completes its initial public stock offering.

1990-1991: GPS is used for the first time under combat conditions during the Gulf War.

1993: U.S. declares Initial Operational Capability of GPS, with 24 satellites in orbit.

1994: FAA announces GPS as the first navigation system approved for use as a stand-alone navigation aid for all phases of flight. FAA also announces the implementation of Wide Area Augmentation System (WAAS) for the improvement of GPS integrity and availability for civil users.

1998: Motorola creates a new "Telematics Information System" business to integrate its GPS, cellular, wireless messaging, and microprocessor design and production capabilities.

5.2.2 Worldwide GPS Market Projections and Trends in Car Navigation and Aviation Markets

Table 12 contains the revenue data of worldwide GPS sales for car navigation, and aviation sectors from 1993 to 2003. Historical data through 1995 is based on 1995 U.S. GPS Industry Council estimates. Data from 1998 to 2003 are market projections by car navigation and aviation market segments according to the U.S. Department of Commerce report mentioned above (ref. 27).

Table 12. Worldwide GPS Sales in two market segments.

Year	Car Navigation WW Sales (\$Millions)	Aviation WW Sales (\$Millions)
1993	100	40
1994	180	62
1995	310	93
1996	520	125
1997	900	160
1998	1600	220
1999	2300	300
2000	2900	380
2001	3600	500
2002	4200	600
2003	4700	710

Car navigation has grown more slowly in the North America than expected (ref. 27). This appears to have been due to the challenge of creating comprehensive, up-to-date digital maps and the market requirements for more sophisticated software that could provide reliable directions and not just show a vehicle's location on a map. As a result, Europe and Japan have the largest segment of the GPS-based car navigation industry worldwide (based on 1998 data).

Worldwide GPS sales in the aviation market have been smaller than the sales in car navigation as indicated in Table 12. Figure 11 shows the GPS worldwide sales in car navigation and aviation markets comparatively. Both growth curves follow a typical product life cycle, which basically includes introduction, growth, and maturity and saturation periods. The car navigation market is expected to show more rapid growth for the next few years, but eventually slowing down as the market saturates. The aviation market is relatively small, but a rapid growth is expected after 2001, as new wide-area augmentation systems become available. It is clear that there is strong correlation between car navigation and aviation market trends. Although the aviation market is small, it is likely to follow a similar path to the car navigation market over a longer period of time.

The total GPS market, including all market segments, is expected to continue to grow in the next few years due to increasing integration of GPS with other information technologies. Increasing number of companies prefer providing GPS-enhanced products rather than the core technology, due to the higher margin of integrated products. GPS alone has become close to a commodity product. The Growth of the GPS market also depends on continuous reduction in the costs of GPS electronic units, as well as the cost of their integration into other information technologies.

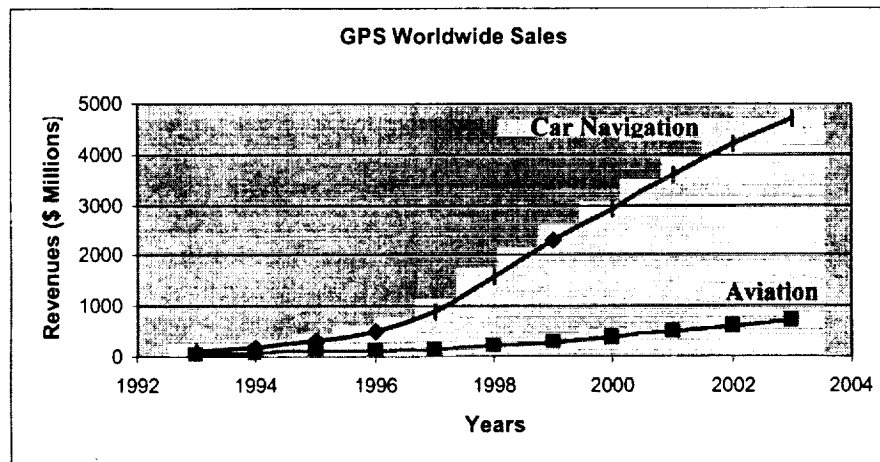


Figure 11. GPS worldwide sales in car navigation and aviation markets.

Cost reduction can be seen from computer / processor board area and power usage. According to the U.S. GPS Industry Council data, GPS PC board area has got smaller dramatically from 50 sq. inches in 1991 to 25 sq. inches in 1993, and approximately 0.5 sq. inches in 2000. GPS power consumption has declined from 3 W in 1991 to around 1.7 W in 1993, and approximately 0.1 W in 2000. Due to these developments, the cost of basic GPS chipset has declined from \$800 in 1991 to \$400 in 1993, and around \$30 in 2000 (These are all approximate values since they are taken from related graphs of U.S. GPS Industry Council). Figure 12 and 13 show the cost drop of GPS basic chipset due to the decline in GPS PC board area and power consumption respectively, from year 1993 to 2000. 1991 and 1992 data have been excluded since they are out of the time period of this GPS market research.

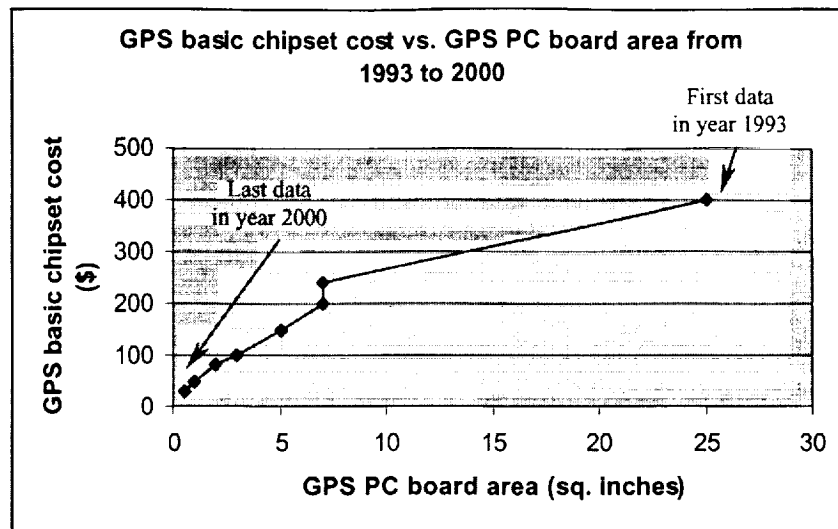


Figure 12. Decline in the GPS basic chipset cost due to smaller PC board area (1993 – 2000).

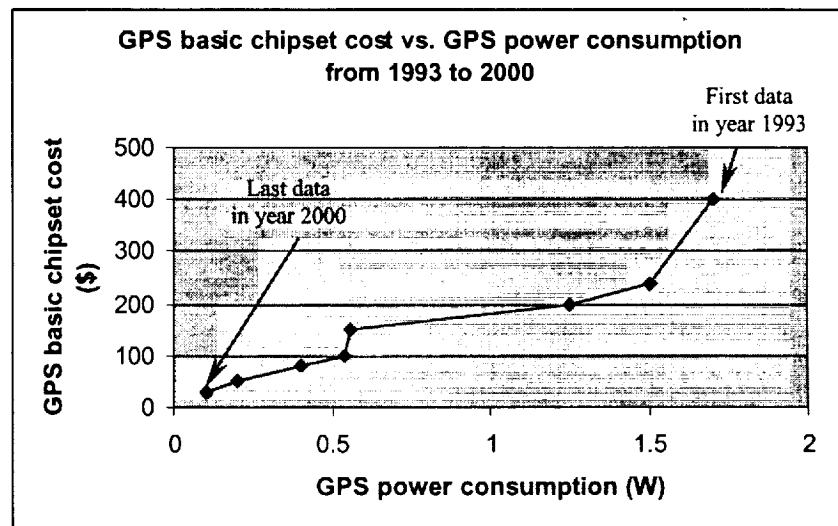


Figure 13. Decline in the GPS basic chipset cost due to less power consumption (1993 – 2000).

This data indicates that GPS PC board area became 95% smaller from 1993 to 2000, while power consumption decreased by 94%. GPS basic chipset cost also declined by 92% in this period as seen in Figure 12 and 13. Similar curves can be drawn for personal computers and telecommunications equipment (ref. 27). These declines are typical for information technologies. U.S. firms generally price GPS business and professional products as a percentage of the user's productivity gains. Such gains are determined by return on investment data that are known within 6 – 12 months of product deployment. As a result, user demand is driving product evolution with product cycles of 12 – 18 months, which also is typical of an information technology.

Another trend in the GPS market is the increasing value added contribution of embedded software to user applications. The ultimate value of GPS to the user is in the application of the information, which is largely recovered from the GPS signal by software. GPS hardware is getting smaller and smaller as it

becomes integrated into the silicon structure that encompasses communications and computation. In commercial markets, the increased software content is the fundamental driver for productivity increases and therefore acts to stabilize the unit prices. In the consumer markets, the software is less of a cost factor and the traditional erosion of hardware prices reduces the price at retail levels (ref. 27).

In summary, integration of GPS with other information technologies is important. High-margin GPS products tend to be those with specialized software content or where GPS provides functionality to a high- margin product or service. For example, a \$65 chipset provided by a GPS OEM may be the core of a \$600 car navigation device that pays for itself in saved time and driver convenience. Large number of companies prefer to provide GPS-enhanced products and/or compete using GPS-based advantages (ref.27).

5.2.3 GPS Aviation Market

There are an estimated one million pilots and 400,000 aircraft in the United States alone (based on 1998 data). However, there are differences in the needs of domestic GA and international commercial aviation. GA is a highly price elastic market. According to 1998 data, prices range from \$500 - \$1700, falling to an average of less than \$1000 (ref. 27). This substantiates to the price points of information systems provided to the trucking industry, which is around \$1,700 as the non-recurring cost (section 3.3). It also resembles the price range found in the survey analysis, in which 41.6% of the participants would like to pay less than \$2,000 as the non-recurring cost for new weather information systems (section 5.1.6).

Figure 14 shows the increase in worldwide GPS sales in the total aviation market (GA is a proportion of this market) as opposed to the decline in GPS basic chipset cost. According to this data, as the GPS cost decreases by 92%, total worldwide aviation sales increase by 89.5%.

GPS usage has also grown in the GA market. Based on 1993, 1995, and 1997 data in GA fact cards (ref. 29), it has increased from 15.7% in 1993 to 35% in 1995, and 41.7% in 1997 as shown in Figure 15. Although additional substantiation of this growth pattern could not be found, it appears that the GA market is likely to follow the same growth curve of total aviation market (Figure 11).

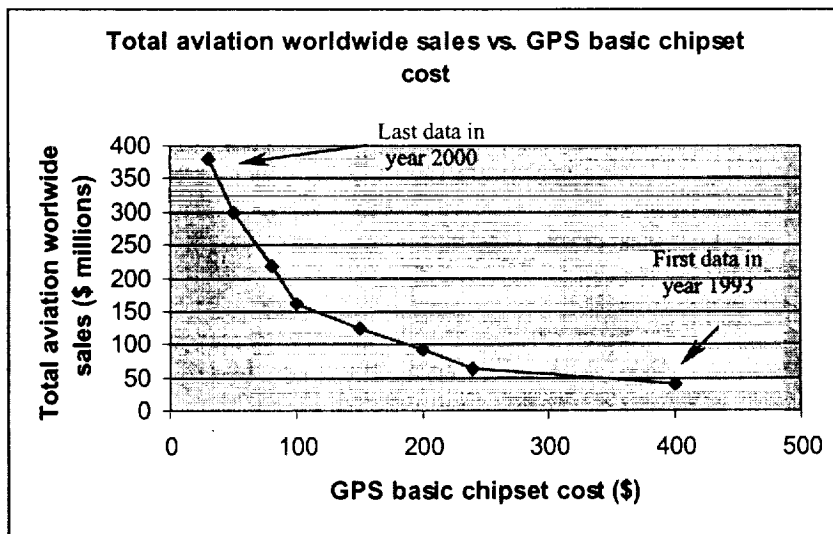


Figure 14. Total aviation worldwide sales rise while GPS basic chipset cost declines (1993 – 2000).

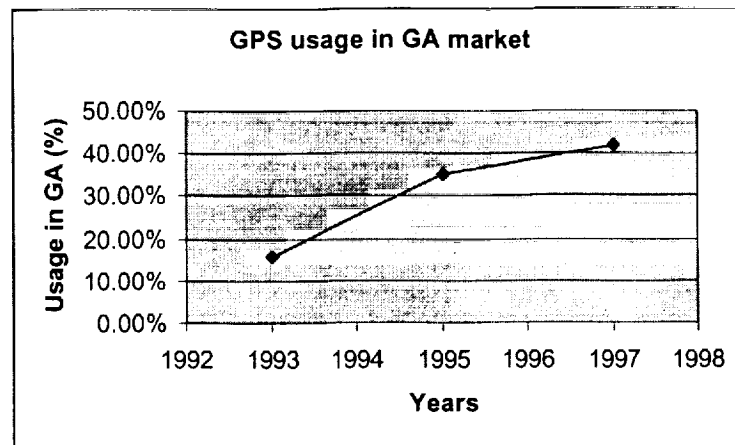


Figure 15. Growing GPS usage in GA market (1993 – 1997).

5.3 Current General Aviation Market Activities and Products

A cockpit weather information product has recently been introduced to the aviation market: FlyTimer - WxMate. FlyTimer Corporation is an aviation systems integrator, providing safety-related solutions for general and commercial aviation. WxMate is a new product of FlyTimer, which consists of a Palm IIIc connected organizer loaded with FT2000 software, a 12-channel GPS receiver, 760-channel VHF transceiver and antenna equipment. All this and following information is taken from the FlyTimer's web site at www.flytimer.com.

Basic features of this new product is as follows:

- Near real-time weather, such as NexRad and other graphic products, including nationwide lightning strike images. Graphic and text information is provided by ARINC's GLOBALink, by using the ACARS network.
- Two-way communication between the aircraft and the ground.
- Runway incursion information.
- Electronic flight/kit bag.
- Integrated checklist.
- Phone patch over ARINC system through radios (HF, VHF).
- Available custom designs.

The three main components of the WxMate system are:

- Ground-to-Air-to-Ground Communication Network. ARINC's ACARS network currently operates more than 350 ground stations in North America. The ARINC ground stations contain DSPs (Digital Signal Processors) that are connected with a VHF communications transceiver through a microcomputer. The ground station sends the message via high-speed landline to the CPS, where it is further routed and processed according to the information contained in the message header. The CPS will generate an acknowledgement and uplink it back to the plane.
- Ground-Based Systems. The WxMate system develops a request in the air on the PDA and sends that request through the air-to-ground network to these servers. In turn, the computers and servers develop and encode responses to these queries and transmit them on the ground-to-air ACARS network to the airplane. The system decodes each response and displays the results on the screen of the PDA.

- **Aircraft-Based Components.** The WxMate system has three major components in each airplane, which are transceiver, antennas and CDU (Computerized Display Unit). It also contains an FCC certified 760-channel VHF radio module. This module is somewhat transparent to the user as the PDA with its embedded software is the primary user interface. The system also includes a DSP microprocessor.

The WxMate system is expected to cost between \$2800 and \$6000, depending on system configuration. Text messages are expected to be without any charge, but data will be on subscription basis and will cost most pilots about \$45 per month (according to an interview with the system provider). This product is currently in final certification testing.

Some of the other cockpit weather service providers are: ViGYAN, Capstone, AVIDYNE, Echo Flight, and ARNAV. ViGYAN is seeking capital to bring its pilot Weather Advisor (PWA) system to market. This system delivers near real time weather information to airplanes using a satellite broadcast and graphically displays the information to pilots (ref. 30). Capstone is exploring a digitally powered glass display on the instrument panel, which gives the pilot a variety of information in one place and has different capabilities depending on how it is configured. Navigation maps, terrain information, weather information, and aircraft targets are presented on the moving map-equipped display. The Universal Access Transceiver (UAT) is the two-way digital data link employed in this system (ref. 31). AVIDYNE's FlightMax displays integrate GPS navigation information, traffic information, lightning information (from Stormscope), and terrain on a single display (ref. 32). Echo Flight's Flight Cheetah FL 270 is a portable device, which provides GPS navigation, graphical weather, terrain alert, messaging, and airport information. Weather information is provided by request/reply via satellite transmission (ref. 33). ARNAV has developed a graphical cockpit display of weather information using a low-cost datalink for ground-to-cockpit transmission for GA. It provides e-mail messaging from the cockpit. GPS navigation, graphical display on cockpit management systems, and wireless datalink communications technology have formed the hardware basis for the "Weather in the Cockpit System (ref. 34)."

5.4 Technological Implications of Automobile and Trucking Information Systems for General Aviation

This chapter identified a number of advanced wireless and device technologies that will enable the growth of mobile information systems in the A/T sector and that have possible applications in the general aviation sector. Section 4 discussed others including display and voice recognition technologies, software applications and satellite and terrestrial networks that deliver broadband data services. These are examples of technologies, which may have implications for the airborne mobile device user.

Although aviation is one step ahead in the system architecture definition as compared to the terrestrial ITS program, there are a number of technologies and products that can be considered to be common to the requirements of the A/T industry, as well as the aviation arena. Developments in wireless communication technology are constantly enabling more feature-rich, cheaper, lighter and power efficient wireless and portable terminals. For example, various methods are being developed for driving bit error rates down and increasing performance (multi user detection for interference rejection, advanced coding schemes such as turbo codes, adaptive antennas which contribute to more efficient utilization of the frequency bands, etc.).

The cellular handset, which is far more sophisticated than a wireline handset, incorporates powerful, high-speed microprocessors and DSPs. It is also rapidly shrinking in its form factor while having advanced capabilities such as voice recognition, and handwriting input. This has been made possible by miniaturization, and developments in semiconductor technology and ASIC (Application Specific Integrated Circuit) design.

Combined modulation and coding schemes such as Trellis coding improve performance due to sharing information between different parts of the data stream to enable 'soft decisions' and better bit error rate performance. Complex hybrid modulation techniques such as $\pi/4$ QPSK, GMSK, QAM and OFDM provide greater spectral efficiency. The use of advanced compression algorithms such as the Lempel-Ziv algorithm helps to make the transfer of large amounts of data possible.

A method of increasing performance, which is gaining popularity, is the use of diversity combining, which leads to a diversity gain, and translates into better error performance for the same transmitted power. There are two main methods of exploiting diversity:

- Spatial Diversity (several antennas)
- Time Diversity (using a special type of receiver, the 'RAKE receiver' to combine the information obtained from components of the signal arriving with different delays i.e. multipaths)

Figure 16 shows how the combining is performed on a number of received signal replicas. The power of this system is that replicas of the desired signals can be obtained from:

- more than one source or transmitter of the signal e.g. more than one satellite,
- signals received at different times from a number of different multi-paths, or,
- received at two or more antennas.

Multi-rate schemes are being developed to support a number of different user profiles and multimedia applications whereby the equipment can transmit at a number of different data rates that can be changed in real time depending on the mode of use. In a CDMA system, this can be achieved by multiple-spreading factor or multi-code schemes; a combination of these is used in the W-CDMA standard. In a TDMA system, the number of time slots can be varied. The frequency assignments in a FDMA system are fixed and hence data rate cannot be varied in an FDMA scheme. One of the new technologies that aim to exploit the benefits of multiple rates and other flexible parameters is software radio.

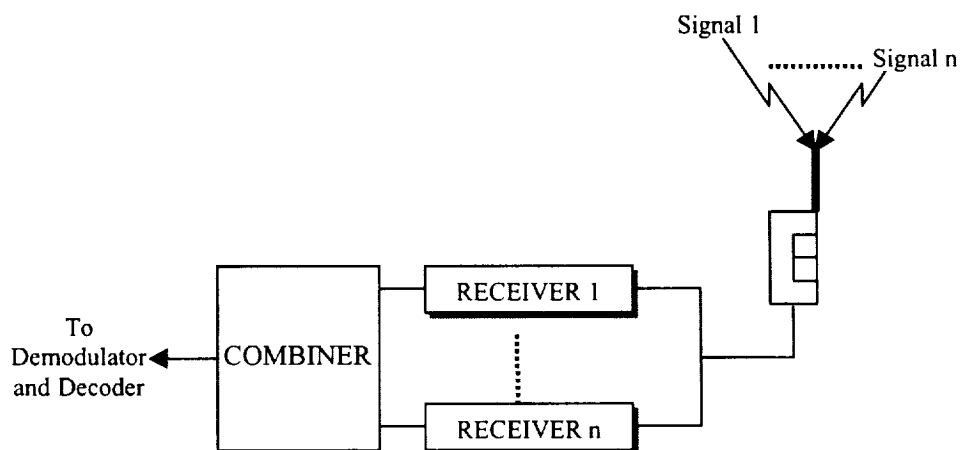


Figure 16. Diversity combining in a mobile radio receiver.

5.4.1 Software Radios

Software radios are developed to address functionalities that are critical to the successful implementation of future mobile communication standards. Software radios are characterized by over-the-air change of communication scheme/ protocol (e.g. support for both W-CDMA and GSM on one device). It facilitates the use of sophisticated terminals that are network aware and re-configurable. This issue will be more important in the future, considering the heterogeneity of network platforms and terminals that will co-exist. Application Protocol Interface (API) is capable of delivering a service, which the underlying network and the terminal can support, to the user. Development of this interface is a key issue, especially when roaming from a bandwidth rich environment such as a terrestrial network towards a bandwidth limited satellite network.

Software radio implementation involves two key concepts: channelization and sample rate adaptation. This is achieved by the use of a re-configurable architecture consisting of FPGAs (Field Programmable Gate Arrays) and high-speed Digital Signal Processors (DSPs). In software radios the digitization of the whole channel bandwidth is done at IF frequencies. This puts a huge processing burden on the Analog-to-Digital Converters (ADC's) and the signal processing components. The technology associated with these sophisticated terminals is a topic for current investigation.

6 Conclusions and Recommendations

This study identified current on-board information systems used in the A/T industry, and determined their key characteristics. It provided a background to work on possible implications for new technology penetration in the GA industry.

According to historical development of such technologies worldwide, ITS programs are launched as a result of traffic problems such as urban congestion, increased cost from time devoted to traveling, accidents, rising road deaths, safety, security, and environmental pollution. Driver errors are one of the primary causes of accidents, and new on-board transportation systems including integration of electronics, computers and telecommunications are expected to reduce these problems. These studies are conducted by the cooperation of public and private sectors. The public sector usually initiates, supports, and leads the ITS studies while the private sector contributes to the funding, R&D projects, and applications. General objectives of using on-board information systems are: providing on-board route guidance and navigation, fleet management, traffic and travel information (such as road works, parking, location of major facilities, emergency information of weather conditions, pollution monitoring and advisory systems) through various communication systems (such as cellular phones, and in-vehicle computers), and facilitating the development of driver assistance safety products. The use of on-board information systems is rising dramatically worldwide, due to increasing number of users preferring vehicles equipped with these systems.

In the trucking industry, the communication method is generally either satellite, cellular, or radio. There are also separate or integrated GPS systems on-board. Text messages are most common for communication between the driver and the dispatcher. Displays are usually either separate, or integrated into the front panel or a laptop. Data entry is done by using either a touch screen display, voice by cell phone, or a keyboard. There are many services provided to the trucking industry such as maintenance and performance monitoring to the driver, emergency alert, automatic location information to the dispatcher, configurable business forms and templates, optional printer, fax, pager, special function buttons, black box, etc. Information system providers in the trucking industry are considering the following developments on their products in the future: Internet access on-board, traffic information services integrated with route optimization, increased capacity and baud rates, and voice recognition for communication.

In the automotive industry, the communication method is usually cellular based. Communication is often provided by either text, or voice messages (by cell phone), or both, primarily by communicating with an assistance center, which provides most of the information that the driver needs. For navigation, integrated or separate GPS devices are provided. Data entry to the system is usually by using special function buttons. System services can be grouped as maintenance and performance monitoring such as automatic airbag deployment notification to the assistance center, roadside assistance such as traffic updates and weather information to the driver, and other services such as stolen vehicle tracking, and satellite radio subscriptions. Future developments will include more voice recognition for hands-free communication, more integrated systems into the front panel, advanced Internet access, and more information about the traffic and weather conditions ahead.

Based on this market search, it can be concluded that the driver in the trucking industry is more like a pilot who communicates with the dispatcher frequently, and the truck is like an aircraft that is being tracked by the dispatcher at certain time intervals. The dispatcher has a relatively similar role to ground stations in aviation. In one of the trucking systems, even a black box is provided in case an accident occurs. This parallel is due to the fact that the information systems are used for business purposes, and for managing a fleet of trucks that travel to different destinations in this market. Driver and truck safety is

important, and monitored by deployment of features such as maintenance and performance monitoring to the driver, and automatic emergency alert signal to the dispatcher.

On the other hand, the automotive industry is more concerned about the convenience of the user. Automotive companies provide on-board services such as satellite radio subscriptions, and personal web sites for the driver. There are tracking services in this area as well, but it is usually occasional such as stolen vehicle tracking. Driver safety is also important so that there is emergency signal service to the assistance center as well. In both markets (automotive and trucking) however, similar developments are being considered. The driver in a truck will be able to use Internet for business communications, but for personal messaging as well. In both markets, advanced Internet services are desired. For communication, voice recognition is the most popular technology for its convenience, and probably due to the demand for hands-free communication (in some U.S. states, using cell phones are already illegal while driving due to safety concerns). More traffic and weather information is also considered necessary in both industries.

Partnerships between automobile manufacturers and information system providers are also interesting. This usually results in a combined program, department, or even a new company, which is responsible for creating, marketing, and maintenance of such systems. For example, Ford partners with Qualcomm, which is an information system provider for the trucking industry as well. This partnership creates the Wingcast system. Similarly, Mercedes obtains hardware and software from Motorola, and emergency response service from Protection One, for its TeleAid system.

In searching these markets, a number of enabling communication technologies have been selected for studying based on their usage for the purposes of the A/T industry, and their possible availability for GA cockpit information systems. This study included both wireless data networks, such as private mobile radio networks, MMDS, satellite data networks, third generation cellular networks, and device technologies for wireless connectivity including operating systems, air interface/wireless modem, and Bluetooth. Challenges to deployment of these technologies are also discussed and solutions have been suggested.

Various services, interfaces and device technologies studied in these mobile communication systems highlight how certain underlying technologies are common to many applications. An example of this is the need to transmit location data by the user in a terrestrial navigation system and the control center to communicate the traffic or map information. Information databases are present either in remote servers or in portable in-vehicle CDs. The advantage of having local fixed information databases is that it significantly reduces the bandwidth required for transmission and increases speed. Therefore, it is used in most in-vehicle navigation systems and this could be a method for use in aviation applications as well. Software applications are being developed to integrate the cell-phones, PDAs and vehicle electronics, which can have significant impact on resource sharing (e.g. displays and making the user's mobile communication system more seamless with the fixed workspace and communication networks).

After market research on information systems used in the A/T industry and determination of the key characteristics and technologies, it is necessary to characterize the GA market to observe any similarities or differences that can help to understand implications of these systems for GA industry. For this reason, a survey was conducted at the Experimental Aircraft Association (EAA) Convention in Oshkosh, Wisconsin, between July 26 and August 1, 2000, with 139 GA pilot participants. The analysis of this survey provides insight about the key characteristics desired by GA pilots in a future cockpit weather information system as well as current problems they face in terms of weather information. Based on these 139 pilots' inputs, 78.3% of them use weather radio for this purpose. Participants identified problems while using this equipment including lack of clarity (35.1%), communication loss (28.6%), and incorrect weather information (19%). 67.7% of these pilots get weather updates less frequently than every 15 minutes, and they would like to get accurate weather information more frequently than every 5 minutes.

These results indicate that there are problems in this area, and frequent and accurate weather information is essential. As a result, it is clear there is a desire for new weather equipment that can solve these problems.

48.4% of the participants would like to have a system with display hardware integrated into the cockpit's front panel, while 35% prefers a portable system. However, if the system is portable, they prefer it to be integrated into their personal palm pilot or laptop. This means that the integration of the future system into other information technologies is desired. Participants indicated that the following features are most desirable, in their future system:

- Graphical messaging (81.3%)
- Three-dimensional terrain visualization (92%)
- LCD (86%) or color (82.6%) display
- Touch-screen data entry into the system (74%)
- Weather alert system about the conditions ahead (88.3%)
- Non-weather services are close to each other: Aircraft performance report to the pilot with 39%, aircraft location information to the ground with 36%, and Internet access in cockpit with 27%.

With regard to recurring costs, which are annual fees for continuing services, most participants are not willing to pay more than \$500. As a result, independent from the non-recurring costs, which are the costs for purchasing and installing the equipment, recurring costs should be in this range to satisfy these customers. Participants are divided almost evenly in terms of non-recurring costs. 58.4% of them are willing to pay more than \$2,000 up to \$10,000, while 41.6% would like to have a product for less than \$2,000. This may result in two or more different future equipment categories, with similar basic characteristics, but different value added system configurations. The typical cost for information systems in trucking industry is in this range, with \$1700 as non-recurring cost, and approximately \$55 as recurring cost (\$660 annual). Similar services desired by the pilots are currently available in the trucking industry in the cost range that the survey participants are willing to pay.

The Oshkosh survey analysis helps to draw a picture about current problems in GA in terms of weather information, desired system characteristics, and costs for new weather information systems. In the characterization step of the GA market in this research, GPS was considered a good candidate to study as an example of information technology penetration to enable an estimate of the market growth for future information system products, one of them being weather information systems. The important points in GPS market acceptance and their relevance to a new cockpit weather information system are as follows:

- There is strong correlation between car navigation and aviation market trends in terms of GPS sales. *Technology transfer is possible between information systems in automotive industry and aviation.*
- An increasing number of companies prefer providing GPS-enhanced products rather than the core GPS stand alone technology, due to the high margin of integrated products. Integration with other information technologies is always preferred by the customers, and results in more sales. *This is similar for all information systems. The Oshkosh survey analysis indicates a large demand for integrated cockpit weather information systems as well.*
- Growth of the GPS market also depends on continuous reduction in the costs of GPS electronic units, as well as the cost of their integration into other information technologies. For example, GPS PC board area got 95% smaller in a like 7 year period (from 1993 to 2000), and GPS basic chipset cost decreased by 92%. In the same period, total worldwide aviation sales increase by 89.5%. *In similar information technologies, products have short life cycles, and fast technological developments. This can be expected from new cockpit weather information systems.*
- GA is a highly price elastic market. According to 1998 data, prices range from \$500 - \$1700, falling to an average of less than \$1000. While GPS cost decreased by 92%, total worldwide aviation sales increased by 89.5%. *Price elasticity of GA market should affect new cockpit weather information*

systems as well. 1998 GPS prices are in the same range of non-recurring costs determined by the Oshkosh survey.

- The GA market in terms of GPS sales is likely to follow the same growth curve of the total aviation market. *A similar growth is likely to occur for new cockpit weather information systems.*

There are a number of companies whose goal is to provide weather information to the GA pilots, such as ViGYAN, Capstone, AVIDYNE, Echo Flight, and ARNAV. During this research a new cockpit weather information system has been introduced to the aviation market, FlyTimer – WxMate, although it is currently in final certification testing. It consists of a Palm IIIc connected organizer including a special software, a 12-channel GPS receiver, 760-channel VHF transceiver and antenna equipment. According to the FlyTimer web site, it provides near real-time weather graphically, including nationwide lightning strike images. Graphic and text information is provided by ARINC's GLOBALink, by using the ACARS network. It is expected to cost between \$2800 and \$6000, depending on system configuration. Text messages are expected to be without any charge, but data will be on subscription basis and will cost most pilots about \$45 per month. These cost ranges are also similar to non-recurring and recurring costs indicated in the Oshkosh survey analysis. It provides graphical and frequent weather data, and it is integrated into a palm pilot. Although graphical data and integration to a palm pilot are second choices of the survey participants, they still have high percentages. Therefore, if the final certification testing is completed successfully, this may be a good in-cockpit weather information system for GA market.

Consequently, there are common grounds in the A/T information systems and future GA cockpit weather information systems, even though operating environments differ. This study identifies key characteristics and enabling technologies in A/T systems, problems and desired characteristics in new GA cockpit weather information systems, and possible development and market acceptance of these new systems based on GPS historical development data. It may be possible to apply some of these technologies to the GA environment. This requires a new study for more detailed analysis of a number of key technologies that have been identified in this research. An upcoming study will include a software test-bed, which will test technical compatibility and performance in the aviation environment. Additionally, an integrated product model with parameters such as costs, features, and market analysis will give a measure of the worth of the new product. FAA certification issues were not a part of this study. However, they can be a part of the new research if necessary.

Abbreviations

3GPP	Third Generation Partnership Project
A/T	Automobile and Trucking
ACARS	Aeronautical Radio Incorporated Communications Addressing and Reporting System
ACTS	Advanced Communications Technologies and Services
ADC	Analog-to-Digital Converter
AMPS	Advanced Mobile Phone Service
AMTICS	Advanced Mobile Traffic Information and Communication Systems
AOPA	Aircraft Owners and Pilots Association
API	Application Protocol Interface
ARDIS	Advanced Radio Data Integrated System
ARINC	Aeronautical Radio Inc.
ASIC	Application Specific Integrated Circuit
ASTM	American Society for Testing and Materials
ATIS	Advanced Traveler Information Systems
ATM	Asynchronous Transfer Mode
ATMS	Advanced Traffic Management Systems
ATT	Advanced Transport Telematics
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CDU	Computerized Display Unit
CED	Common European Demonstrators
CRT	Cathode Ray Tube
CSD	Circuit Switched Data
DBS	Direct Broadcast Satellite
DOT	Department of Transportation
DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe
DSMA	Data Sense Multiple Access
DSP	Digital Signal Processor
DSTN	Dual-scan STN
EAA	Experimental Aircraft Association
EDGE	Enhanced Data Rate for GSM Evolution
EIA	Electronics Industries Association
ERTICO	European Road Transport Telematic Implementation Coordination Organization
ESA	European Space Agency
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
FPGA	Field Programmable Gate Array
GA	General Aviation
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Groupe Special Mobile
HSCSD	High Speed CSD
HSD	High Speed Data
HUD	Head-Up Displays
IEEE	The Institute of Electrical and Electronics Engineers
ION	Institute of Navigation Systems
IPDS	Inmarsat Packet Data System

ISDN	Integrated Services Data Network
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITSA	Intelligent Transportation Society of America
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
IVHS	Intelligent Vehicle Highway Systems
IVI	Intelligent Vehicle Initiative
IVIS	In-Vehicle Information Systems
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEO	Low Earth Orbit
LOS	Line-of-sight
MEO	Medium Earth Orbit
MMDS	Multichannel Multipoint Distribution Service
MOA	Mobitex Operators Association
MOMUSYS	Mobile Multimedia Systems
OFDM	Orthogonal Frequency Division Multiplexing
PDA	Personal Digital Assistant
PLMN	Public Land Mobile Network
PROMETHEUS	Programs for a European Traffic with a Highest Efficiency and Unprecedented Safety
PSTN	Public Switched Telephone Network
RCA	Rain Compensation Algorithms
QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase Shift Keying
RACS	Road-Automobile Communication Systems
RF	Radio Frequency
RTT	Radio Transmission Technology
SAE	Society of Automotive Engineers
S-DARS	Satellite Digital Audio Radio Service
SINUS	Satellite Integration into Networks for UMTS Services
SMS	Short Message Service
SSVS	Super Smart Vehicle System
STN	Super Twisted Nematic
S-UMTS	Satellite UMTS
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TDMA	Time Division Multiple Access
TFT	Thin Film Transistor
TIA	Telecommunications Industry Association
TOMAS	Inter-trial Testbed of Mobile Applications for Satellite Communications
UPC	Uplink Power Control
UMTS	Universal Mobile Telecommunications System
UTMS	Universal Traffic Management System
VDR	Variable Data Rate
VICS	Vehicle Information and Communication System
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
WAP	Wireless Access Protocol

W-CDMA

Wideband Code Division Multiple Access

References

1. Intelligent Transportation Society of America web page: <http://www.itsa.org>.
2. ITS America: *Strategic Plan for Intelligent Vehicle Highway Systems in the United States*. Washington, DC, 1992.
3. Drane, C., Rizos, C.: *Positioning Systems in Intelligent Transportation Systems*. Artech House, Norwood, MA, 1998.
4. Nwagboso, C. O.: *Advanced Vehicles and Infrastructure Systems, Computer Applications, Control and Automation*. John Wiley & Sons, West Sussex, England, 1997.
5. National Highway Traffic Safety Administration: *Traffic Safety Facts Report*, 2000.
6. Intelligent Vehicle Initiative: *IVI Business Plan*, July 2000.
7. U.S. Department of Transportation News, July 19, 2000.
8. ITSA news, *Automotive Telematics on the Start of Explosive Growth Cycle*, <http://www.itsa.org> (September 4, 2001).
9. ITSA news, *New Technologies to Alter the Future of Transportation Industry*, <http://www.itsa.org> (November 1, 2001).
10. ITSA news, *North American Telematics Market Projected to Surge to \$7 Billion by 2007*, <http://www.itsa.org> (August 14, 2001).
11. ITS America: *National ITS Program Plan, Volume 1*, Washington DC, March 1995.
12. Murray C., "Automakers struggle with speech recognition technology", December 2000, EE times web page: [<http://www.eet.com/>].
13. Saltkintzis A.K.: *A Survey of Mobile Data Networks*. IEEE Communication Surveys, 1999.
14. Mobitex Operators Association web page: [<http://www.mobitex.org/>].
15. Ericsson Mobile Communications AB: *Mobile Data Communication Guide to Mobitex*. Ericsson Mobile Communications AB, Mobile Data Division, ESPIDER-164 80 Stockholm, Sweden, 1993.
16. Qualcomm web page: [<http://www.qualcomm.com/globalstar/about/>] , 2001.
17. The Boeing Press Release: [<http://www.boeing.com/news/feature/farnborough2000/m-connexion.html>].
18. XM Satellite Radio Inc. web page: [<http://xmradio.com>], 2001.
19. Sirius Satellite Radio web page: [<http://www.siriusradio.com>], 2001.
20. Radio Industry web page: [<http://radioindustry.about.com/cs/digitalsdar/>], 2001.
21. Press release Delphi Automotive Systems: [<http://164.109.59.132/news/pressReleases/pr324-01032001>], 2001.
22. WorldSpace Corporation web page: [<http://worldspace.com>], 2001.

23. Telephonic conversation with Sirius Radio representative, August 2001.
24. Telephonic conversation with XM Radio representative, August 2001.
25. Barani B., Schwarz da Silva J., Pereira J., Arroyo-Fernández B., and Ikonomou D.: *S-UMTS in the Wireless Information Society: The Challenges Ahead*. European Commission, DG XIII-F.4.
26. ACTS Project AC212 SINUS: *Satellite UMTS Radio Access Specification*. Deliverable 23, June 97.
27. Pace, S., Wilson, J. E.: *Global Positioning System, Market Projections and Trends in the Newest Global Information Utility*. The International Trade Administration, Office of Telecommunications, U.S. Department of Commerce, September 1998.
28. Chien, C.: *Wireless Access for Next-Generation Internet*, Third Annual International Symposium on Advanced Radio Technologies, 2000.
29. AOPA GA fact cards, 1993, 1995, 1997.
30. ViGYAN web page: <http://www.vigyan.com/software.shtml>.
31. Capstone web page: <http://www.caasd.org/proj/capstone/avionics.html>.
32. AVIDYNE web page: <http://www.avidyne.com/EX5000/default.htm>.
33. Echo Flight web page: http://www.echoflight.com/pdf/FL270_Brochure.pdf.
34. NASA news, [http://technology.nasa.gov/scripts/nls_ax.dll/w3SuccItem\(202337\)\)](http://technology.nasa.gov/scripts/nls_ax.dll/w3SuccItem(202337))), NASA Success Story, Weather in Cockpit System, October 2000.

Appendix A – Another Weather Information Product: TeleType GPS

During the submittal process of this report, new information about current aviation market activities has been encountered. Another weather information product will be introduced to the aviation market by TeleType Company, which is also related to general aviation. TeleType Company is a software development company based in Boston, founded in 1981 (www.teletype.com). It specializes in software system integration, especially in integrating the GPS with handheld computers. This GPS software includes support of Windows CE (Palm Sized-PC's, Handheld PC's, H/PC Pro, v2.12, v3.0, SH4, MIPS, Strong Arm), or a Pocket PC computer for vehicle navigation, fleet tracking, and geographic information systems data collection. Current hardware solutions include low power GPS receivers. However, the company is now expanding to support additional emerging technologies for GPS solutions based on satellite communications and two-way paging. TeleType GPS aviation software is composed of two basic products: the TeleType GPS Aviation Maps, and the TeleType GPS Flight Planner. The aviation maps can also be loaded into the standard TeleType GPS street mapping software.

TeleType is planning to provide en-route weather information for pilots, by adding real time weather feature into its GPS products (<http://www.teletype.com/pages/gps/aviation.html>). According to an email communication with the company, the new product will be introduced to the aviation market at the Aircraft Owners and Pilots Association (AOPA) airshow in November 8-10, 2001 in Ft. Lauderdale, Florida. A picture of their GPS screen with weather information is included below. This picture was taken from the company's web site at <http://www.teletype.com/pages/gps/weather.jpg>.

This new information underlines the importance of technology integration in the information technology systems. Multipurpose products are popular and manufacturers want to rapidly provide products and services for the consumers through technology integration. It also emphasizes that weather and other information services in general aviation, and in aviation in general, are getting more and more interest from both information system providers and consumers. The aviation market is getting more profitable for these providers, similar to the historical development of the automotive and trucking market. Rapid developments are expected in the aviation market.

